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PRACTICAL ESSAYS

ON

MILL WORK

AND OTHER

MACHINERY,

BY

ROBERTSON BUCHANAN, ENGINEER.

The Second Edition Corrected,

WITH NOTES AND ADDITIONAL ARTICLES,

CONTAINING NEW RESEARCHES ON VARIOUS MECHANICAL SUBJECTS,

BY THOMAS TREDGOLD,

CIVIL ENGINEER,

MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS.

Illustrated by 20 Plates and numerous Figures.

VOL. II.

ON THE CONNECTIONS AND COUPLINGS OF SHAFTS, DISENGAGING AND RE-ENGAGING MACHINERY IN MOTION, EQUALIZING THE MOTION OF MILLS, THE THEORY AND VELOCITY OF WATER WHEELS, CHANGING THE VELOCITY OF MACHINES IN MOTION, THE FRAMING OF MILL WORK, &c.

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ON THE

CONSTRUCTION AND DURABILITY

OF THE

LONGITUDINAL CONNECTIONS OF SHAFTS,
DENOMINATED COUPLINGS.

ESSAY III.

PREFACE.

HAVING attempted to treat of Wheels and of Shafts, both of which may be considered as essential parts of Mill-work, the next subject in point of order which occurred to me, was *the means of connecting Shafts longitudinally*, denominated Couplings, which accordingly forms the subject of the present Essay.

In examining this subject, I have collected and described a number of different methods which have been employed of coupling shafts. These methods are arranged under two classes;

practical observations are made on each coupling. These observations I presume not to say are entirely free from mistake, but they are the result of experience, not my own only, but compared with that of many others well acquainted with the subject, with whom I have taken many opportunities of conversing; nor will these observations be altogether without benefit, should they only lead those who may be better qualified to make others more extensive, judicious, and useful.

A number of facts relative to the subject are also stated, which I trust will not be without advantage. For however useful abstract reasoning may be, yet a theory excluding some apparently trivial or minute circumstance, is often rendered altogether uncertain in its application to practice. Of this we have remarkable instances in calculations made not many years ago by some of the most eminent philosophers then in Europe, relative to the motion of water in canals and pipes. The Academy of Sciences at Paris over-estimated the quantity of water to be delivered by an aqueduct so far, that it was, when executed with the greatest care, found to be deficient in the proportion of five to nine. The celebrated Desaguliers made an error of five

parts out of six; and the no less celebrated M'Laurin of ten parts out of eleven, in estimating the water to be conveyed for supplying the city of Edinburgh.*

Mr. Smeaton was certainly well able to appreciate science, yet he seemed to place more value on the writings of practical men than those merely of a theoretical nature.

"I have myself (says he) always found that exact accounts of buildings [*and of course, of other such works,*] which were in any degree remarkable, and actually executed, were much more instructive to my mind than *systematical* writing.†

* Professor Robison mentions these circumstances in the Ency. Brit. art. River. This subject is now better understood. See Phil. Trans. Hydraulic Investigations, subservient to an intended Croonian Lecture on the Motion of the Blood, by Dr. Young. Read before the Royal Society, May 5, 1808.

† See Description of Eddystone Lighthouse, p. 7.

It is to be regretted that the professional learning of an engineer had been so little cultivated as to render it necessary for Smeaton to gather the chief part of his instruction from the practical experiments of his predecessors. No doubt different minds require different modes of instruction; nevertheless a systematic course of study seems to be vastly pre-

But while I speak thus in favour of practical works, I mean not to depreciate those of science. They may be of great mutual benefit, and while we listen with reverence to the voice of experience,* by sound reasoning on her dictates, we may extend and apply them to purposes more various and useful than those to which they originally related. I shall conclude this preface in the words of Professor Robison, which seem to me more appropriate than any I could use to express the same ideas.

ferable to a desultory course, and also to have been preferred by all teachers either of art or science. But men advanced in years, and full of occupation, have seldom either inclination or leisure to follow a systematic course. They seek for information only when compelled by professional difficulties. They rely upon force of genius to supply the wants of the moment, as an Indian hunter on his exertion in the chase; and like him they have no idea of laying up a stock to provide for unforeseen exigencies. How different would be the powers of a man, of equal genius, with the advantage of a systematic course of study; where reasoning was joined with experiment! Might we not then look forward to a time when theory and the laws of nature would be merely different terms for the same thing? It is not however to be expected that this perfection will ever be attained while theory is confined to matter divested of its natural properties. (Ed.)

* "Experience, slow preceptress, teaching oft
The way to glory by miscarriage foul."
COWPER.

"The man of science who visits our great manufactures, is delighted with the ingenuity which he observes in every part, the innumerable inventions which come even from individual artisans, and the determined purpose of improvement and refinement, which he sees in every work-shop. Every cotton-mill appears an academy of mechanical science; and mechanical invention is spreading from these fountains over the whole kingdom: but the philosopher is mortified to see this ardent spirit so cramped by ignorance of principle, and many of these original and brilliant thoughts obscured and clogged with needless and even hurtful additions, and a complication of machinery which checks improvement even by its appearance of ingenuity. There is nothing in which this want of scientific education, this ignorance of principle, is so frequently observed, as in the injudicious proportion of the parts of machines and other mechanical structures; proportions, and forms of parts, in which the strength and position are nowise regulated by the strains to which they are exposed, and where repeated failures have been the only lessons."

Glasgow, Jan. 1809.

ON THE

CONSTRUCTION AND DURABILITY,

&c.

CHAP. I.

On the Longitudinal Connections of Shafts denominated Couplings.

208. It is well known to those who are in any degree acquainted with mill-work, that it is very frequently necessary to convey motion much farther than would be practicable by any one shaft; it is therefore, often requisite to connect two or more shafts together.* These connections are denominated *couplings*, and may be divided

* For, though it be most desirable that machinery should be concentrated as much as possible, long ranges of lying shafts are unavoidable in large mills, in cotton, linen, and woollen manufactories, breweries, &c. &c. Hence the efficient and durable connection of these shafts is an object of considerable importance. (Ed.)

into two classes; viz. 1st. Those having *two* bearings: 2nd. Those having *one* bearing. I mention couplings having two bearings, first, because they were long in use before those having *one* bearing, and because they are, generally speaking, more simple in their construction.

CLASS I.

Of Couplings with Two Bearings.

209. By the *bearings* of shafts are meant the parts which support their pivots, arbours, or journals. When a coupling has double bearings, each shaft is supported by two bridges, as represented A, B and C, D, Plate V. Fig. 1.

COUPLING I.—FIG. 1 & 2.

Of the Square Coupling.

210. This kind of coupling is formed by making the ends of the shafts to be coupled, square. These squares project beyond the journals, and are in the spaces B C and

D E, between the bridges. One of the squares is made as long as what is called the *coupling-box* F. The use of the coupling-box, which is made of iron, is to receive both the squares, so as that when the one shaft is moved, the box connects it with the other shaft in such a manner that they must move together. But when occasion requires, the box may be slipped back upon the longest square, and so give liberty to take out any one of the shafts, independently of the rest, however great the number may be. When the shafts are engaged, the box is kept in its place by the pin G.

The coupling at B C is represented as engaged, and at D E as disengaged.

Fig. 2. represents this kind of coupling upon a larger scale. The same letters refer to the same parts, as in Fig. 1.

Sometimes, instead of the section of the couplings forming a square, as Fig. 2, No. 2, it is made of an oblong form, as represented in Fig. 2, No. 3; but this form is more difficult of execution than the

square. Also, instead of having the coupling-box solid, it is frequently made in two pieces, Fig. 2, No. 4, in which case it embraces the whole length of both squares, there being no occasion then for room to slide back the box in order to disengage the couplings.

Observations.

211. Were the axes* of these shafts truly in one straight line, and the squares made and fitted to the box with perfect accuracy, the motion would be perfectly smooth, but in large machinery this is almost impracticable, and even if practicable when new, would not long continue to be the case. The brasses wear unequally, or the framing sinks more in one place than another. In some part of each revolution, therefore, one or other, or both the shafts, will be lifted off their bearings. The two adjoining journals then come to act like one twisted piece of iron, and must obviously occasion an unsteady motion, and

* *Axis.*—The line, real or imaginary, that passes through any thing on which it may revolve.

much friction. This imperfection is sometimes called a *lift*. This kind of coupling has, for these reasons, been in a great degree abandoned for mill-work. But in smaller machinery, such as in coupling the rollers of those machines for spinning cotton called *mules*, it is still used; because in that kind of machinery it can be executed with a very great degree of accuracy, and is not so liable to wear out of truth as in larger works.

212. Of this species of couplings with double bearings are many varieties, made according to the whim of different workmen; such for instance, as is represented in Fig. 3, which has a small projection from each angle of the square, differing in no other respect from the common square coupling, and liable to nearly the same faults.

COUPLING II.—FIG. 4.

Of the Round Coupling.

213. The round coupling has the parts

between the bridges cylindrical. The coupling-box C is made to fit those parts, and to slip backward when occasion requires, as was described of the square coupling. When the shafts are engaged, two bolts, D E, and F G, pass through the box at right angles to each other, and one of them through each of the shafts; this being done, when the one shaft is moved, it will evidently carry round the other along with it.

Observations.

214. The effects of the round coupling are nearly the same as the square coupling, but as the parts may be all turned, it is more easily made true at first; and when the bolts which prevent it from twisting, wear, they may, with little trouble, be renewed; but, as the whole stress comes on a small surface at these bolts, both the bolts themselves, and the holes very soon wear. For this reason, after this kind of coupling was some time tried for the rollers in cotton spinning, it was abandoned, and the square

in which the strain is diffused over a greater surface, substituted.

COUPLING III.—FIG. 5.

Of Clutches or Glands.

215. Couplings which have no coupling-boxes, are denominated *clutches* or *glands*. They may, without impropriety, come under this class of couplings having *double bearings*.

Fig. 5. represents a coupling of this kind, it consists of two crosses, A A and B B, one fixed to each shaft; B B has its ends bended forward, and lays hold of A A, and thus turns round the other shaft.

Observations.

216. Glands are an excellent mode of coupling for *double bearings*, and have the advantage of throwing the stress further from the centre of motion, than in the square coupling as commonly executed; but few workmen are able to execute glands with accuracy, and if this be not

the case, they make a very disagreeable movement; it may therefore be not improper to describe how this may be accomplished.

217. When the axes of two journals are put as near to a straight line as possible, by observation from the workman's eye, it often happens, that they may be in a bad situation for working, either because the axes do not really correspond, or, even though they did correspond, yet the arms of the glands do not take hold both together, or perhaps from both causes. To adjust these arms, observe, in the *first* place, when the glands turn round, if one of the tails be in continual contact, and the other tail always preserve an equal distance from being in contact, in that case, the centres are perfectly opposite, and axes in one line, and consequently right; but if the distance of the other point of the glands vary in its distance, or becomes so irregular, as to free the other point of the gland, then, in that case, the

centres are wrong, and must be so adjusted, that one point of the gland bear equally all round, while the other preserves an equal distance. The *next* object is, to adjust the points of the glands so that they be both in contact. This may be done by chipping and filing, and in that case, they will convey themselves all around in contact with each other.

COUPLING IV.—FIG. 6.

BORING-MILL CLUTCH.

First Construction.

218. Fig. 6. represents a boring-mill clutch; A B C is a round plate of cast iron firmly fixed on the shaft M, next the moving power; D E is a lever connected with the boring-shaft N, but which is moveable in one direction on a bolt at F, so that it may be moved to lay hold of the projections H, H, H, H, on the plate A B C, which carries round the lever D E along with it, and so moves the boring-shaft N; by pulling the lever backward, the boring

shaft N may be stopped at pleasure. It is represented in Fig. 6, No. 1, as disengaged.

Observations.

219. This kind of coupling is applicable to such cases only as have the motion very slow. Pressing on one side only of the centre, although the axes of the shafts should not be exactly on a line, there will be no lift. For the parts, in that case in contact, slide upon one another.

220. It is found, however, to have a great tendency to force the bridges O, P, on end. In order to lessen this tendency, the projections H, H, should be made as far from the centre as conveniency will admit.

COUPLING V.—FIG. 7.

BORING-MILL CLUTCH.

Second Construction.

221. This coupling, like the first construction, has a lever D E, for disengaging

and re-engaging; but instead of being hung immediately from the end of the shaft, turns on a bolt at F in a large cast-iron plate I K L. The other parts having the same letters of reference as Fig. 6, resemble them, and are for the same use. There are three spare sets of ears, Q Q, &c. (which support the lever near the point of pressure) cast on the plate I K L, to be used in case of those in action breaking.

Observations.

222. The manner in which the lever D E is hung in the plate I K L, at a distance from the centre N, and is supported near the point of pressure by the ears Q Q, takes the stress entirely off the bolt F, and indeed off the lever D E, except near the ears Q Q.

223. This, therefore, is evidently a stronger and better clutch, and is accordingly used in boring the larger cylinders, whereas, that on the first construction is generally used for the smaller kinds of work.

COUPLING VI.—FIG. 8.

224. Fig. 8. This coupling is constructed by having two round cast-iron plates, A B and C D, of the same size and form. Each of these plates has a part F, cut out, Fig. 8, *f g h i*, No. 2, and a projection L, corresponding to the part cut out. The projection of the one plate is inserted into the opening in the other, and thus serves to engage the shafts.*

Observations.

225. This coupling is simple and durable. It is in fact a species of *glands*, (Art. 215.) It affords an excellent mode of adjustment. The pivot and hole for fixing the plates ought to be round, and the end of the shaft turned along with the journal.

* A slight variation of this coupling has been found a very good one. It consists in making the circular heads toothed, so as to fit together; the teeth being wedge shaped. This mode of coupling is not affected by any slight variation or settlement of the bearings, and it is very durable. (Ed.)

When the couplings are fitted into each other, care should be taken that those parts of the clutch which are opposite each other will take hold together.

Shafts coupled upon this plan, when occasion requires, are easily moved out of their places, independently of each other.

COUPLING VII.

226. Fig. 9, Plate VI. represents the *coupling-link* used by Messrs. Boulton and Watt in their portable steam-engines. From one of the arms A, of the fly-wheel, projects a strong iron pin P. On the end of the shaft R, which is to be coupled to that of the fly-wheel A B, there is a crank C, which has the same length of an arm that the pin is distant from the centre of the fly-wheel. The pin and the crank are connected by a link L, so that when the fly-shaft moves, it carries round the other shaft R, along with it.

Observations.

227. This is a very simple and durable

contrivance, and if the two shafts be only parallel to each other, they may work with great smoothness, although their axes should be in different lines, for the links, in that case, move without any twisting. But if the axis be not parallel, or if they be not in one line, a twist will take place at the link, which may be injurious.

The crank ought to be considerably longer than those in general use, to prevent, as much as may be, the continual drag on one side of each of the journals.

COUPLING VIII.

228. Fig. 10. represents a coupling, which is sometimes used to convey motion from the fly-wheel shaft A, of a steam-engine; and is so contrived, that in case the fly should turn the wrong way, the mill-work remains at rest, and so prevents accidents. This effect is produced by means of a joint C, on the arm B, resembling the joint of a table, or of a pocket foot-rule. When the fly-wheel turns the proper way, the arm D, upon the end of

the fly-shaft, acts against the face of the arm B, on the mill-shaft F; and as the joint does not yield in that direction, the mill-shaft is carried round by the fly-shaft. But, if from any accident, the fly turns the wrong way, the arm D strikes the back of the arm B, the joint yields, and the mill remains at rest.

Observations.

229. This coupling may be made sufficiently durable. Its principles are nearly the same as the boring-mill clutch, Fig. 6. In the Repertory of Arts and Manufactures, Vol. II. p. 19, is a description of an alteration on the cattle-mill, to answer the purpose of these couplings, in making the mill go in its proper direction only. I was led to this contrivance from the accidents to which carding machines were liable when driven by horses, and in the year 1790 I erected several mills on that plan.* I observe it has since been simplified and applied to thrashing mills.

* The plate referred to in this paper, will serve to

General Observations.

230. All other couplings having two bearings, that I recollect having seen, from the reasons already given, are attended with much friction. From that fault, they have in a great measure been abandoned, and those with one bearing substituted.

231. It is, however, proper here to remark, that although the friction, and expence of erection of couplings with one bearing, are considerably less than those having two bearings, where the chief object is to convey motion to a distance, or where there is no great weight or lateral stress on the shafts, yet all circumstances should be duly considered before adopting either plan: for if heavy drums or wheels

give some idea of the manner in which mill-work was constructed about the year 1790, in this part of the Island. Cast-iron was then but little used in cattle-mills. See introduction to *Essay Second, on the Shafts of Mills.*

are to be placed near both ends of the shafts, or any other thing that will occasion much lateral pressure, it will be advisable to use two bearings. I shall, in the next chapter, proceed to examine couplings having *one* bearing.

CHAP II.

CLASS II.

Of Couplings having one Bearing.

SECTION I.

232. This class of couplings when properly constructed, has, to a certain degree, the property of being flexible in all directions, like the well known contrivance invented by Dr. Hook (Fig. 11.) called the universal joint. This joint is sometimes constructed by a cross, as represented in the figure, and sometimes with its four pivots fastened at right angles, upon the circumference of a hoop, or on the surface of a solid ball. The moving parts are evidently alike in all these cases.

233. It is sometimes applied to communicate motion, instead of beveled gear, when the angle does not exceed 30 or 40

degrees, and where the number of revolutions is to be continued the same; also where equality of motion is not required, for as it recedes from a right line, its motion becomes irregular. The property of the universal joint to which I allude, of conveying angular motion, is of great use when it can be attained in couplings, in order to allow for the inaccuracy which arises from the settling of the framing or the wearing of the brasses. It need not, however, yield further than what is really necessary for that purpose, which is so little, that no irregularity of motion that can be hurtful in practice can arise.

234. The disadvantage of the universal joint, as represented by Fig. 10, and as commonly made, is, that it has not sufficient strength to resist great strains. I shall, however, afterwards describe a modification of it, well adapted to bear very considerable stress, (see Fig. 18. Art. 247.)

235. Most part of the couplings de-

scribed in Chap. I. may with some small addition or alteration, be converted into couplings having one bearing, of this description *is the square coupling.*

COUPLING IX.

The Square Coupling.

236. It consists of a square coupling-box C, Fig. 12, which fits a square on the end of each shaft. The square of the shaft A, is close to its journal. The square of the shaft B is at the end furthest from its journal.

In order to support the square of B, and keep it on a line with A, there is a round hole D, bored out of the centre of the square of B; to fit this hole, there is a round projection D, from the square of A. Instead of having the projection D, sometimes there is a hole in the end of both shafts, into which is fitted an iron or steel dowel or pin.

The coupling-box C, covers both squares. It is kept in its place by two iron pins or bolts, G, G, one of which passes through

each shaft. These bolts also serve to keep the shafts from withdrawing from each other.

Observations.

237. This coupling is used with good effect in conveying motion through a great length of shafts, where there is but little lateral pressure; but where there is much lateral pressure, for instance in *drum-shafts*, which give motion to carding engines by belts, it has been found, that the round projection and socket soon wear and get loose. This fault perhaps arose, from the square being too small to admit the projection, and the socket to be sufficiently large. But though this be a better mode of coupling than many in use, yet, the difficulty of having the squares accurately adjusted is great, as is also the fitting of the inside of the coupling-box, from the ordinary mode of casting. For these reasons, in many cases it is very liable to lifting or straining.

238. In England, most of the rollers of those machines, denominated *mules*,* for spinning cotton, have but one bearing; the end of one roller being squared and inserted into the end of that next to it, as represented in Fig. 13. But as there is a great lateral pressure, the end of the roller is liable to wear and become wide, and occasion a hobbling and inaccurate motion. From the accuracy required in *mule* and *throstle*† rollers, it is not only necessary that the axes be exactly in one line, and accurate in their diameters, but also that

* The *mule* was invented about the year 1777, by Mr. Samuel Crompton, formerly of Hall-in-the-Wood, near Bolton, in Lancashire, a person of very great ingenuity, and to whom the country is indebted for many other useful improvements; this machine probably received its name for having rollers like Arkwright's machine, at the same time, that it retained the carriage and spindles of hand-spinning machines called common jennies.

In 1769, Mr. Arkwright obtained his patent for spinning, and in 1775, for preparing cotton by machinery.

† *Throstle*, a machine for spinning cotton, compounded from the inventions of Arkwright and Crompton.

they run true without hobbling or jolting. By any method I have yet seen, this is not attainable in one bearing; even though the utmost attention of the most accurate workmen has been bestowed to accomplish this end. In Scotland, two bearings are generally used in the coupling of all rollers employed in spinning cotton.

COUPLING X.

Of the Round Coupling.

239. This coupling having only one bearing, is represented by Fig. 13; and has similar additions to those of the last described coupling, Fig. 12; and which will appear sufficiently from the figures, without further description.

Observations.

240. The observations which were already made on the round coupling with two bearings (Art. 214, Fig. 4.) are in a great measure applicable here, as are those relative to lateral stress, in the observations (Art. 237.) on Coupling IX.

COUPLING XI.

241. Fig. 14 represents a coupling used in several of the mills at Manchester. It consists of a scarfed joint, (like that used in carpentry,) and when the shafts are engaged, it is firmly bolted, as shewn in the figure.

Observations.

242. It was probably owing to the defect relative to lateral stress mentioned in observations (Art. 237.) Coupling IX. that this contrivance was adopted. But it seems to me to have all the defects attending the solid shaft with more than two bearings, namely, that it could not for any length of time move properly on all its bearings, without a continual bending of the solid metal, which would occasion a waste of power, besides a great risk of breaking the shaft.

COUPLING XII.

243. The coupling represented by Fig. 15, Plate VII. is only a variety of coupling

XI. and, therefore, the same observations are applicable to this also.

COUPLING XIII.

244. That shewn in Fig. 16, may also be considered as only another modification of Coupling XI. the one shaft being firmly fixed to the other by flanches and bolts. The same observations are also applicable here.

COUPLING XIV.—FIG. 17.

245. Has the bearing and the joint of the coupling at the same parts of the shaft, so that the journal is not solid, but composed of the ends of each shaft, which are there formed into quadrants. Each shaft having two projections, corresponding to two recesses in the other, one of the projections is represented at A, No. 1. as engaged; No. 2. represents the coupling as disengaged.

Observations.

246. This is obviously so bad a contrivance, that I need say little with regard to

it. The bad effects of it were lately brought under my observation at an extensive set of calico printing-works. It is there applied to drive dash-wheels for washing calicoes, and has been attended with great trouble and expence; for the shafts are very frequently breaking at the couplings, and are thus rendered useless. Besides, while they do last, the couplings thus formed in the journals, must act as a kind of cutters, and produce great friction, and tear down the brass.

COUPLING XV.—FIG. 18.

247. It consists of three distinct parts, A A, B B, and C C; A A and B B are, each of them, firmly fixed to its respective shaft, and are so formed, that they join partly into one another, in some degree, like the parts of a common *papier maché* snuff-box.

C C consists of a solid ring of cast iron, into which is screwed four strong steel or wrought-iron pins D, D, D, D. These pins serve to act as the four pivots of the

universal joint already described in Fig. 11.

A A and B B are so contrived, that each of them lays hold of two opposite iron pins, the whole combined thus, forming an universal joint. There is a space of about a quarter of an inch left between A A and B B, in order to allow the joints to play; and A A and B B are commonly made about 14 inches diameter outside.

There is a small mortise in each pin, to receive a cotteril, to prevent the pin from coming out in the course of working.

In the plate, so many different views of this coupling are given, that it is hoped no further description will be required.

Observations.

248. This coupling is somewhat expensive in its first erection; but it being evidently, as far as is necessary in such a coupling, a complete universal joint, from its durability and saving of power which its pliancy must occasion, it seems to me per-

haps the best thing of the kind that has yet come under my observation.

COUPLING XVI.–FIG. 19, PLATE VII. & VIII.

249. Is a kind of coupling which has been lately executed at Manchester. The coupling-box C is made very long, and is square in the inside, excepting at D E, where there is a kind of partition, with a large round hole truly bored in it. Into this hole, each of the shafts A and B, are accurately fitted. The round part of the shaft B, however, is made so long, as to allow the liberty of slipping back the coupling-box, in order to disengage the shafts. When engaged, the box is kept in its place by the pin B. H represents the journal.

Observations.

250. The principles of this coupling, are nearly the same as those of the common square coupling, (X. Fig. 1.) (Art. 210.) but the greater length of the box, as well as the greater strength of the round parts intended to keep the axis true, give this last coupling very material advantage.

251. This kind of coupling has another advantage which the greatest part of single bearing couplings have not, viz. When the coupling-box is shifted off, any shaft may be taken out, without affecting those adjoining.

COUPLING XVII.

252. Fig. 20. Plate VIII. represents a coupling used in one of the cotton mills last erected, and one of the most extensive at Glasgow. The external part, coupling-box C, is cylindrical. On the inside, the parts A, A, A, A project, and are fitted into the shafts, which have similar projections E, E, E, E fitted into the coupling-box. Through the centre of the coupling-box, there passes a bolt H H, to keep it in its place; and, at the further ends of the row of lying shafts, they are kept together by working against a kind of step formed of brass. Were this not the case, two bolts would be necessary in each coupling, to keep the shafts from separating.

Observations.

253. The advantages of this kind of coupling, seem to be these two, 1st, The projecting parts E, E, &c. can be accurately turned and fitted to the coupling-box. 2nd, These projecting parts tending to the centre, are strong, and little liable to wear.

SECTION II.

Of the Couplings of Upright Shafts.

254. Hitherto we have considered couplings for lying shafts only. But of upright shafts, little need be said, having in general little lateral pressure, they are seldom made with two bearings; so that, by placing any one of the couplings with one bearing, already mentioned, in a vertical position, an idea will be obtained of the mode of coupling upright shafts.

The square coupling (IX. Fig. 12, Plate VI.) for instance, may easily be applied to an upright shaft.

COUPLING XVIII.—FIG. 21.

255. A represents the journal of the lower shaft, (which is almost always that which has the bearing,) B is the lower end of the upper shaft, and C the coupling-box.

COUPLING XIX.—FIG. 22.

256. A represents part of the under shaft, B the lower end of the upper shaft, C the journal. The termination of A is made square, to correspond with which there is a socket formed in B, which answers the purpose of a coupling-box.

Observations.

257. This coupling is often used for light work, particularly in flour-mills, for connecting the feeder with the top of the stone-spindle.

COUPLING XX.—FIG. 23.

258. A represents the lower shaft, D the upper, which is above the journal. Projecting and receding quadrants, the same as in Fig. 17, serve to connect the shafts.

Observations.

259. This is a very good and simple mode of coupling upright shafts. By their own weight, together with that of wheels that may be on them, the projecting and receding quadrants D, D are pressed home into their holds, and are not subject to get loose in their sockets or clutches, which would be the case, were the shafts lying horizontally.*

* A great many other schemes for couplings have been introduced; most of them ingenious; but I have not examined any, which are sufficiently simple and likely to be durable, to offer here as improvements. (Ed.)

CHAP. III.

General Observations.

260. It may be proper to observe, that the larger the parts of the coupling can conveniently be made, the better. In other words, the further the point of stress is from the axis, the couplings will be the more durable. This being a thing to which too little attention in practice is paid, it will not be improper here, in a popular way, to endeavour to explain the reasons of this greater durability.

261. The strain on the point of stress, is inversely as the velocity of that point. (Essay II.) Now the revolutions being the same in a given time, the further the point of stress is from the axis, the greater will be the velocity of the point, and, consequently, the less the stress. Experience has taught this to those unacquainted with science; for every one knows, that a hand-

spike, capstan-bar, or other similar lever, requires to be largest near the fulcrum, (or point on which it turns in raising a weight,) and may be diminished in proportion to the distance from the centre of motion.

262. Thus, for example, at two feet from the centre, the stress is only one half of what it is at one foot from the centre. This is almost evident to the feeling, from the force the hand has to apply at those different distances. Now, the larger the parts are, the stress must be thrown the further from the centre of motion, and the acting parts will, therefore, be the more durable. Hence also the advantage in machinery of having large wheels and large pullies. (See Essay I. *General Observations on the Wheel-Work of Mills*, Art. 74.)

263. It is also proper to observe, that when there is a long line of shafts, the couplings, where there is only one bearing,

should, if practicable, be so arranged, as that the unsupported end of the shaft should be as far as may be from the part subject to lateral pressure. For instance, in Fig. 21, Plate VIII. the couplings and journals are better as there represented, than had they been at A A, in the middle, between the wheels.

264. The oiling of couplings is found to render them more durable. This fact has been fully ascertained in one of the most extensive cotton manufactories in Britain, in the machinery of which the couplings were formerly very liable to wear, but, since using oil, they have been found sufficiently durable.

265. Since learning the circumstance respecting the effects of oil, I find, that the squares of couplings nearest the journals, from accidentally getting oil, are least worn.

266. A fly-wheel is often of use in a

long line of coupled shafts; I may here mention, that, in the vicinity of Glasgow, motion is conveyed from a steam-engine by means of lying shafts, to the distance of ninety-three yards. When those shafts were first tried, from the spring of so great a length of shafts, and the play of the couplings, the motion at the further end was so very irregular, that it could not be applied to work a calender. A fly-wheel near the calender, connected with the lying shaft by pullies and a belt, was resorted to as a cure for this evil. This simple contrivance had the desired effect; and the calender has ever since given satisfaction in its work.

A table respecting the dimensions, stress, and durability of couplings is annexed.

267. *Facts respecting Couplings.*

	1. Resistance, horses' power.	2. Revolutions per min.	3. Years at work.	4. Side of square in inches.	5. Length of box.	6. Power divided by Revolutions per min. or proportionate strain.
A, Cast Iron. Square Coupling, one bearing (see Coupling IX. Fig. 12.) coupling next the steam-engine, worn off each angle of the square about three-fourths of an inch; the square was originally 5 inches; the box 10 inches long	16	40	7	5	10	.40
B, Cast Iron. Same line of shafts, further on; all things but the resistance the same. Some of the couplings not perceptibly worn, others worn off about three-eighths of an inch at the angles	8	40	7	5	10	.20
C, Cast Iron. Same kind of couplings as A and B, square originally 6 inches, box 12 inches long, not perceptibly worn	17	38	5	6	12	.44
D, Cast Iron. Same kind of coupling, not perceptibly worn	6	38	5	3	6	.15
E, Wrought Iron. Same kind, much worn	1	38	5	2	5	.02
F, Cast Iron. Same kind, not worn	12	50	8	4½	8	.24
G, Cast Iron. Worn one half inch	9	55	4	4	8	.16
H, Cast Iron. Not perceptibly worn	12	50	7	4	6	.24
I, Cast Iron. Not perceptibly worn	6	50	7	3½	5	.12

Description of the Table.

Column 1 contains the resistance in horses' power.

Column 2 contains the revolutions per minute.

Column 3 contains the years at work.
Column 4 contains the side of the square in inches.
Column 5 contains the length of the box.
Column 6 is found by dividing the power by the revolutions per minute, which represents the comparative stress, (see Essay II. Chap. III.)

Observations.

I.

268. These couplings do not seem to have been durable in proportion to their stress; but this may be in part at least accounted for, from difference of workmanship, and of degrees of hardness of metal, or perhaps accidentally getting oil.

II.

269. Two circumstances must materially affect the *durability* of couplings. 1. The extent of surfaces in contact at the place of pressure. 2. The distance of the surface of pressure from the centre of motion.

It is probable, therefore, that all other

circumstances being the same, the durability of couplings increases in a ratio compounded of those two circumstances, or nearly as the *squares* of the sides of such couplings as have square coupling-boxes.

Thus, for example, B, in the table, is 5 inches on the side; admitting the above ratio to be near the truth, in order to have the case A made in proportion to B, it should be increased to rather more than 7 inches, for

The square of 5 is equal to 25, and as the stress on A is double, 25 multiplied by 2, is equal to 50, the square root of which is 7.07.

III.

270. But we may suppose it prudent to take a standard somewhat larger than the side of B, for all the additional weight of the parts would never be felt hurtful in practice; let us suppose 6 inches therefore a proper standard for eight horses' power, at forty revolutions per minute.

Then the square of 6 is equal to 36,

and 36 multiplied by 2 is equal to 72, the square root of which is 8·5 nearly, or the size which the coupling A ought to have had.

IV.

271. I have, in Observations II. and III. considered cases in which the revolutions per minute were both the same; but I conceive, that *velocity* must materially affect durability, because the grinding or wearing, where there is any play, must be increased by an increase of velocity.

V.

272. With respect to durability, couplings may be considered under two distinct classes.

1. Those having boxes.

2. Those without boxes, having legs, such as glands, &c.

The durability of the latter class, will probably increase, all other circumstances being equal, nearly in the ratio of the distance of the parts of pressure from the centre of motion. For, in glands, the

pressure is commonly confined to a small space compared with that of coupling-boxes.

Supplementary Observations.

I.

273. The durability of couplings depends upon so many circumstances, that it is difficult to form general rules with regard to them. The two circumstances already mentioned, (Art. 269,) are important, but others merit at least equal consideration; the angle which the surface makes with the direction of the motion. Thus a square coupling will be more durable than an octagon of the same size, because the acting surface makes a greater angle with the tangent, to the circle in which the acting part moves. A right angle to the tangent, or the radius will be the maximum.

II.

274. The durability of couplings depends greatly upon the accuracy of the

execution. For instance, a well-fitted square coupling, will have one fourth, or perhaps one third of the surface of each side acting. But if fitted as is common in practice, they will have little more than the corners acting. One half of each side is the maximum.

III.

275. As square couplings of a large size are commonly fitted, there is so little of the surface acting, that I suppose their durability will be nearly as the length of the box, multiplied by the velocity of the corners. But if fitted as they ought to be, their durability will be as the rectangle of the acting parts multiplied by the velocity. Or, to simplify the case, (as the ratio will be the same,) as the rectangle of the side, multiplied by the velocity.

These observations may perhaps suggest matter of useful practical reflection to the considerate millwright.

ON THE

METHODS

OF DISENGAGING AND RE-ENGAGING MACHINERY, WHILE IN MOTION.

ESSAY IV.

PREFACE.

THE subject of this Essay is so intimately connected with that of Essay III. on Couplings, that in some cases they are really blended; and while a contrivance is employed for disengaging and re-engaging machinery, it also serves as a longitudinal connection of shafts.

In viewing for the first time a cotton mill, few objects attract more attention, or excite more pleasing surprise, than the facility with which even children stop or set agoing particular parts of the mechanism separately from the rest. But however curious such things may be

to inspect, it is, perhaps, no easy task, on paper, to render them interesting to the reader. Their utility, however, in practical mechanics, will, I hope, stimulate the inquirer to examine with attention, a subject where ornament of style is inadmissable, and where perspicuity alone should be attempted, and which it is perhaps not always easy to attain.

The plan I have followed in this Essay, is similar to that in Essay III. I mean the describing of each method, and making separate observations. What I have in the preface of that Essay said, relative to the observations, is equally applicable here.

However imperfectly executed, I would hope the plan of bringing so many inventions into one point of view, will not fail to be useful to the mechanic, by enabling him more easily to compare them, and more readily to select such as may be best adapted to his purpose.

Glasgow, Jan. 1809.

ON THE

METHODS

OF DISENGAGING AND RE-ENGAGING MACHINERY,

&c.

INTRODUCTION.

276. FROM what has been said respecting couplings, it may easily be understood how shafts may be disconnected when at rest. But many cases in practice require, that particular parts of a mill must be stopped, or set agoing,* without stopping or making any sensible alteration on the motion of the rest of the machinery. In cotton-mills, for instance, this becomes

* When any particular part of machinery is set agoing, it is said among workmen to be *set on*, or *put in gear*; when stopped, *set off*, or *put out of gear*.

absolutely necessary; and there can be no doubt, that necessity, in this case, has given rise to many most ingenious contrivances. Previously, however, to the invention of cotton mills, there were contrivances for this purpose in use; such, for example, as the sack-tackle in corn mills.

277. In order to assist us in forming a judgment of the comparative merits of such improvements, it may be proper to bear in mind, a tendency attached to all matter, which is intimately connected with practical mechanics, but on which daily experience shews too little attention is bestowed in the construction of machinery.

The tendency to which I allude, has, by philosophers, been called *inertia*,* (or more frequently, though with less propriety,

* "A tendency to preserve in a state of rest or uniform rectilinear motion, is a property attached to all matter, and may be considered as proportional to the mass or weight of a body." (Young's Nat. Phil. vol. i. p. 51.)

*vis inertia**) by which is meant, the tendency which every piece of matter, when at rest, has, to remain at rest; and, when in motion, to continue in motion. In other words, the impossibility of *instantaneously* producing motion in a body, or, of *instantaneously* stopping a body in motion. It is this tendency, therefore, that occasions those violent shocks in attempting to set bodies suddenly into motion; and those shocks, besides tending to destroy the machine, occasion a very great loss of power. Some part of the machine must break, or at least yield to this potent law.

[A. 277.] The practical mechanic, and perhaps also the philosopher, will find it some advantage to dismiss the term *inertia* from the place it occupies in science. When properly understood, it simply in-

* *Vis inertia* is defined by Newton, (Def. 3. Book I.) to be a power implanted in all matter, by which it resists any change endeavoured to be made in its state; that is, by which it becomes difficult to alter its state, either of rest or motion.

dicates that matter never changes its state, unless there be a change in the power or powers acting upon it.

If you consider inertia as a power, it must be identical with the power of gravity in one case, with the momentum of a body in another, with the power of magnetism in a third, with friction in a fourth, and so on throughout the whole of the powers in nature; but many writers write as though it were a real power, and distinct from all these, and consequently lead their readers into incorrect notions on the subject.

It is easily proved, that when a body is struck by another in motion, some time is occupied in communicating the motion from the point struck to the other parts of the body; and therefore, if the parts receiving the blow have not sufficient elasticity and cohesive power to destroy the whole momentum of the striking body till the motion be transmitted to the centre of rotation, it must necessarily break the body struck.*

* The rules for estimating the power of materials

Hence any part of a machine intended to be acted upon suddenly by a moving power should be strong but yielding, or it may be capable of sliding with much friction on the body to be put into motion. (Ed.)

278. Let us illustrate this by example. Throwing a wheel *into gear*, very often occasions the breaking of the teeth, whereas a pulley is generally put in motion by a belt so gradually, that no part of the machinery can receive any injury. In the first case, the wheel being firmly fixed on its shaft, can yield little to *inertia*, [the moving force.] In the last, there is the elasticity of the belt, as well as the liberty of slipping on the pulley to yield to the *inertia*, [moving force,] till by its friction, the belt gradually brings it into motion.

279. This subject naturally divides itself into the two following sections:

under these circumstauces may be found in my Practical Essay on the Strength of Cast Iron, Sect. VII.

I.

Of Methods used when motion is communicated by means of bands, belts, or chains.

II.

Of Methods when motion is communicated by means of wheel-work.

METHOD I.

The Sliding Pulley.—FIG. 1, PLATE IX.

280. The sliding pulley is one of the oldest contrivances for disengaging and re-engaging a machine moved by a belt or band. The pulley P, which is driven by the mill-work, and gives motion to the machine, is not fixed dead on the axle A B, but has a hollow cylindrical *bush* made of metal, accurately fitted to the axle, so that it may revolve easily upon it, and slide a little backward and forward.

In order to make the pulley P carry round the axle A B, there is a cross piece or gland D E firmly fixed to it. On the side of the pulley which is toward the cross, there is one or more teeth T, when

the pulley P is moved toward the cross D E, the teeth lay hold of it, and thereby carry round the axle. By sliding it backward, though the pulley still continues in motion, the teeth T are disengaged from the cross D E, of course the axle stops, and with it the machine to which it gives motion.

The bush C, of the pulley, projects a little upon the side opposite the teeth, and has a groove cut in its outside. Into this groove, a lever F G lies, but so as not to prevent the motion of the bush. By moving the lever F G the bush is moved along with it, and thus serves to disengage or re-engage the pulley.

Observations.

281. For a long time this contrivance was applied to cotton carding machines. The shock, however, proceeding from *inertia*, (Art. 277,) occasioned by the teeth striking against the fixed cross in setting the machine agoing, was very great, and apt to shake the cylinders loose from their

axles. This is a very great defect, and for such purposes as I have mentioned other methods more perfect are now used.

METHOD II.

The Bayonet.—FIG. 2.

282. The pulley or binder A, is kept in motion by a belt. It has a bush fitted to the upright axle B C, and runs always at the same height.

On its upper side, the binder A has teeth T, T projecting upward; above is a pulley, or other piéce of wood or metal D E, fixed to the shaft B C, through holes in which passes the legs F, G of the bayonet.*

* Instead of the legs of the bayonet passing through holes, as here described, it is sometimes made square in the inside, so as to fit a square part of the shaft; which square answers the purpose of the piece of wood or metal, viz. That of carrying round the bayonet along with the shaft. The bayonet has sometimes one leg only; on other occasions it is made like a face-wheel, having a number of projecting teeth or legs. Indeed, it is almost obvious, that all or most of the contrivances which are mentioned in this Essay, must be variously

The bayonet is represented by Fig. 2, No. 3. It is merely a piece of metal with two or more legs, which project downward. The part H is made hollow to receive the shaft, and has a groove into which I K fits, and the lifter moves it upward or downward, serving the same purpose as the lever F G, Fig. 1.

When the bayonet is dropped downward, it lays hold of the teeth T of the binder A, which immediately carries it round, and this gives motion to the axle B C; all that is required to stop it, is merely by hand to raise the lifter I K, which has a spring or catch to keep it in that situation, until again dropped by the hand of the attendant.

Observations.

283. This contrivance is more perfect than the sliding pulley, Fig. 1; because the

modified, according to circumstances, or the fancy of the artisan. I have only given the way in which they are most generally applied. To give all the varieties, would be an almost endless, and, perhaps, useless labour.

pulley does not require to be shifted in the direction of the shaft, which is often inconvenient, and requires more space. Fig. 2, has however the same defect as Fig. 1, of producing a shock at the instant when the machine is put in gear.

This method is still much used in cotton mills. The figure represents one of the upright shafts of a spinning frame. The same contrivance is often applied to horizontal shafts.

METHOD III.

Of the Lock Pulley.—FIG. 3.

284. This method is somewhat similar to the last described, but instead of a bayonet, it has a lock at A, the bolt of which B lays hold of the cross C C, which is fixed to the axle. The pulley, when disengaged, runs on a bush. K is the key, which is turned by means of a stop, which is made to touch a cross part on the end of the key. The turning of the key throws back the bolt, and so unlocks and disengages the pulley.

Observations.

285. This contrivance is less simple than the bayonet. Nor indeed has the lock pulley ever been generally adopted; a proof that it has not been found of much real use. It was used at Manchester about the time that machines, called mules, for spinning cotton, were begun to be changed from being moved by hand, to receive their motion (as is now general) by power.

METHOD IV.

The Fast and Loose Pulley.—FIG. 4, PLATE X.

286. The pulley B is fixed on the axle A, and the pulley C, having a bush, is loose. The belt or band which conveys the motion, may, at pleasure, either by hand, or by a lever, be shifted from the one pulley to the other. When running on the loose pulley C, the axle stands still; when on the fast pulley B, the axle moves.

No. 1, represents the pulleys as adapted to a belt.

No. 2, represents the pulleys as made

for a rope. The inner ledges are made low, in order that the rope may slide with the greater facility from the one to the other.

Observations.

287. It may be proper here to mention, that, in order to make a belt run properly on a pulley, it is necessary to have the rim of the pulley a little rounded or swelled in the middle. The belt always inclines to that part of the pulley which is of greatest diameter. This curious property is found of great practical use. Until this property was known, it was found very troublesome to get belts prevented from slipping off the pulleys.

288. This contrivance of the fast and loose pulleys, is remarkable for its beautiful simplicity. It is attended with no shock, and is perhaps the most perfect thing yet invented for the purpose, in all cases where it can be applied.

Its application in cotton mills is now general. Never, until it was applied, were

the spinning mules found to give satisfaction, when moved by power. They are now, however, almost exclusively wrought by power. This improvement has not only produced a great saving of labour, but has been attended with another very pleasing effect. It has rendered the employment of the spinner more healthful than when moved by hand. The severity of the hand-labour in a warm and confined atmosphere, had a very unfavourable effect on the constitution.

METHOD V.—FIG. 5.

289. The undermost axle A B is kept by the mill in constant motion. The uppermost axle C D has a bridge at D, in the form of a lever, in order to raise or lower it at pleasure. When the end D of the shaft is raised by means of the bridge, the chain or rope E F is tightened, which causes the axle B to move. But when D is lowered, the chain falls slack below the pulley, on the lowermost shaft A, and thus disengages the shafts.

Observations.

290. This very simple contrivance is used in some parts of England, in corn mills, for the sack-tackle. It is evidently applicable to many other purposes; and it is obvious, that E F may be either a belt, a rope, or a chain. A chain is commonly used when applied as a sack-tackle. In that case, the rope or chain, for taking up the sacks, is wound round the barrel on the axle C D.

SECTION II.

Of the Methods used when Motion is conveyed by means of Wheel Work.

291. When a mill is in motion, we may, with perfect safety, lift a wheel *out of gear*; but in throwing wheels *into gear*, when a mill is in motion, there is great risk of breaking the teeth; it is, nevertheless, often done. Cotton spinners know from experience, that the risk of breaking the teeth is much lessened when the wheel to be thrown *into gear* is previously set in motion by the

hand. This they do by pulling the shaft round by the belt. The reason is obvious. The inertia is lessened by this motion given by the hand to the wheel which is to be thrown *into gear*.

METHOD VI.—FIG. 6.

292. Wheels are often disengaged and re-engaged by means of one of the bridges, A B, which carries the end of the shaft nearest the wheel, acting as a lever, having its *fulcrum* A at one end. The other end B is moveable in one direction, and is raised or allowed to fall, by turning the key C D; when *out of gear* the bridge rests securely on the end of the key, as represented in No. 2, Plate XI. No. 1, represents the wheels *in gear*.

Sometimes the bridge is raised immediately by hand, sometimes by a rope and pulley; in these cases it is held out of gear, by interposing a wedge instead of the key, or by a catch under the end of the bridge.

Observations.

293. This mode of disengaging wheels is sometimes inconvenient for want of room; it has, however, the advantage of having the wheels firmly fixed on the shafts. In falling into gear the ends of the teeth are apt to strike against one another, and there is often a violent shock from the inertia.

In the figures, the wheels are represented the one above the other; but the same contrivance is modified, and applied, when they happen to be in any other relative situation.*

METHOD VII.—FIG. 7, PLATE XI.

294. Instead of lifting wheels out of gear, in order to disengage any piece of mechanism, one of the wheels, instead of being fast on the shaft, has a round bush like a loose pulley, and a clutch, or bayonet, which connects it with its shaft, in a simi-

* The motion of the wheel, as it falls into gear, should be in the same direction as it is afterwards to move in; which will lessen the shock considerably. (Ed.)

lar manner with the bayonet and binder, Fig. 2.

Thus the wheel A, Fig. 7, No. 1, has a bush, and works on a round part of the shaft B. The clutch D, may slide on a square part of the same shaft, and is disengaged or re-engaged at pleasure, by means of the lever E F, part of which is represented as cut off, in order to shew the groove in the clutch into which it acts.

No. 2, is an elevated section of the lever E F, shewing its connection with the clutch D, by means of two iron pins G, G, screwed into two slips of iron H, H, which fit the groove, and are not affected by any oblique position the lever may have.

Observations.

295. This contrivance is sometimes made more convenient than is shewn in Fig. 7, by occupying less space; and although it is subject to a shock at *setting on*, yet it is not so liable to break the teeth as in Method VI.

METHOD VIII.

The Friction Clutch.—FIG. 8.

296. This figure represents the friction clutch; it differs from the bayonet (Method II.) in this respect, that instead of striking on a fast cross, the bayonet or clutch, lays hold of the ears of a screwed hoop, which embraces a kind of drum.

A B represents part of a shaft kept in motion by the mill; C D E a bayonet, which either slips on a square part of the shaft A B, or passes through the arms of a cross P Q, (as represented in the figure,) which cross is fastened to A B.

F G is part of a shaft to be connected with the shaft A B; upon F G a kind of drum or pulley H I K is fastened; this pulley has ledges to keep the screwed hoop L M N O steady.

In *setting on* the machine, the hoop L M N O is carried round by the bayonet or clutch C D E, and by the friction of the hoop on the drum H I K, brings it into motion, in the same easy and gradual

manner that a belt does a machine driven by a pulley.

The hoop, as represented in No. 3, Plate XII. from acting more perfectly as a spring, is found to answer better in practice than that represented in No. 1. and No. 2.

Observations.

297. There is a great deal of beauty in this ingenious contrivance, it may be applied to the largest machinery, and variously modified according to circumstances.* It is obvious that it prevents all the unpleasant and hurtful shock so common in throwing heavy machinery into gear.

It may also be the means of saving lives, for should a person's clothes be laid hold of by the wheel-work, in most cases the hoops would slip on the drum, and allow that part of the machinery to stop, without sensibly altering the general motion of the mill. It may, in this way too, prevent injury to the mill itself, which might arise

* Thus, for instance, it may be applied to the wheel and clutch.—Fig. 7.

from belts getting foul, or from chips falling in among the teeth of the wheel-work.

The friction clutch has been lately applied to frames for spinning flax, and it seems to me, might also, with great advantage, be applied to frames for spinning cotton water-twist.

METHOD IX.

The Friction Cones.—FIG. 9, PLATE XII.

298. This contrivance is similar in its principles and effects to the friction clutch.

On the shaft A (kept in motion by the mill) there is fixed a hollow cone H; on the shaft B is another cone E, the external part of which fits the internal part of H; E is, however, moveable like a bayonet on a square part of the shaft B, and may be moved outward and inward also like a bayonet, by a lever.

When E is moved forward, it rubs on the hollow part of H, and by friction, like the friction clutch, gradually brings the machine connected with B into motion.

Observations.

299. Sometimes there is added a bayonet, passing through a hollow cone, which, should occasion require, gives liberty to lock the shafts quite fast into one another.

The friction cones are sometimes applied to sack-tackles, one of them on this this construction may be seen at Messrs. Meux's brewery.

METHOD X.

Wheels acting by Friction.—FIG. 10.

300. Sometimes wheels are made to act without teeth, as represented in the figure; they move one another by contact, having their circumferences generally made of end grain of wood, which may indeed be considered as forming indefinitely small teeth.

It is evident, that wheels of this kind may work with little noise, and be put into gear, and bear against one another without risk of damage. They are commonly disengaged and re-engaged by a bridge, acting as a lever, on similar principles as described in the case of Fig. 6.

Observations.

301. This species of wheel work has been used with good effect in machinery for raising coal; it is also used, in some cases, in cotton-mills; and has, for a number of years, been employed in a saw-mill by Mr. Taylor of Southampton. "This "principle and method of transmitting "mechanic power," as Dr. Gregory justly observes, "certainly deserves attention."*

METHOD XI.—FIG. 11.

302. The figure represents another application of friction in transmitting mechanic force, but instead of the friction being on the hem of the wheel, as in Fig. 10, it is here applied to the sides of the wheel.

The mode here represented, is successfully put in practice, in a tackle for raising and lowering sacks in a respectable brew-house in London. A is the axle which gives motion to the tackle, upon which is the friction wheel B; upon the axis *a* are

* Gregory's Mechanics, vol. ii. page 498.

the friction wheels C, D, and the roller E, round which the rope winds. The end of the axis *a* runs in a socket in the end of the axis A; the other end, in the brass, is in the post *f*. In raising the sacks, the wheel C is kept fast against the wheel B, by the lever *b*, and catches *c c*.

For lowering sacks, the wheel D is kept against the wheel F, by the lever *b* and weight *d* going over the pulley *e*, and a man holding the line *g* in his hand, makes the friction of D upon E more or less, as is necessary.

Observations.

303. This is a very ingenious and simple machine, and as its principles might be applied in other cases, it is well worth the attention of the mill-wright.

METHOD XII.

Self-disengaging Coupling.—FIG. 12.

304. A represents a shaft, kept in motion by the mill; B C a cast-iron wheel fast on the shaft A, having four projecting

teeth, D, D, &c. of wrought iron; E F, is another similar wheel, with similar teeth, G, G, &c. but is loose on the shaft H, and is made to slide on it, and to act as a kind of bayonet. (Method II.) The teeth project obliquely, as may be seen in the figure.

When the coupling is engaged, the teeth lay hold of one another, and the shaft H, is, by their means, carried round with the shaft A, but when any extraordinary stress comes on the shaft H, the pressure on the oblique teeth forces back the bayonet E F, and disengages the coupling. I K L, is a bended lever, having its fulcrum at K, the bayonet is kept forward by the weight of the part M K, of the lever, during the ordinary stress on H.

When the bayonet E F, is forced back, the lever is held up by a catch, until the coupling is re-engaged by the hand of the attendant. The coupling is represented in the figure as disengaged.*

* In order to succeed in producing this effect, the angle B A C must be somewhat greater than would cause the surfaces to slide upon one another, when acted

Observations.

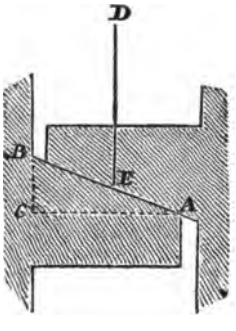
305. This coupling, as it prevents accidents from any sudden stress, is found very useful where turning lathes are driven by wheel-work.

Some good instances of self-disengaging apparatus may be seen in looms driven by

upon by a pressure in the direction D E, perpendicular to A C. Then, when the machine is in motion they would actually slide apart, were it not for the friction on the shaft, and the weight of the lever.

If the angle B A C be less than the angle which would cause the bodies to slide, the coupling would not disengage itself by any force whatever.

According to Coulomb's experiments (see Brewster's Additions to Ferguson's Lectures, vol. ii. p. 155,) the friction of iron on iron is about one fourth of the pressure, hence the angle B A C should be greater than 15 degrees; otherwise the coupling will not disengage. (Ed.)



power. Respecting these machines, I beg leave to refer the reader to Mr. John Duncan's Essays on Weaving, as also to the Edinburgh Encyclopædia, now publishing by Dr. Brewster.*

* It will always be found, that, in engaging by wheels, the teeth will be less liable to be stripped in small wheels than in large ones; because in small wheels the stroke will be made with a less degree of velocity, and also a small wheel requires less force to put it in motion; hence a small and light wheel with strong teeth will seldomer fail than a heavy one. Perhaps the best arrangement will be when the wheel in constant motion is small, and that to be occasionally put in motion a larger one, with elastic arms. These elastic arms might be made in the manner of coach springs. (Ed.)

ON

MECHANISM

FOR EQUALIZING THE MOTION OF MILLS, DENOMINATED LIFT-TENTERS, ENGINE GOVERNORS, AND WATER-WHEEL GOVERNORS.

ESSAY V.

PREFACE.

THIS Essay relates to Machinery not less curious in its construction than useful in practice; and, as some of the apparatus is intimately connected with water-wheels, I hope the papers which are subjoined, containing an account of some experiments* and observations on their velocity, will not be unacceptable to the reader.

* An account of these experiments was originally published in the 10th volume of the Philosophical Magazine p. 178.

ON

MECHANISM

FOR EQUALIZING THE MOTION OF MILLS,

&c.

INTRODUCTION.

306. When a part of the machinery of a mill is suddenly stopped, or suddenly set a-going, and the moving power remains the same, an alteration in the velocity of the mill will take place; it will move faster or slower. Every machine having a certain velocity at which it will work at greater advantage than at any other speed, the change of velocity arising from the above cause, is in all cases a disadvantage, and in delicate operations exceedingly hurtful. In the case of a cotton-mill, for instance, which is calculated to move the spindles at

a certain rate, if from any cause the velocity is much increased, a loss of work immediately takes place, and an increase of waste from the breaking of the threads, &c.; on the other hand, there must be an evident loss from the machinery moving too slow.

In steam-engines this evil is remedied by a contrivance called a *governor*. (Plate XIII. Fig. 1.)—"Two balls are fixed to the ends of rods, in continual revolution, and as soon as the motion becomes a little too rapid, the balls rise considerably," and, by the intervention of a lever, act upon a *throttle-valve*,* which diminishes the quan-

* *A throttle-valve* is formed by a plate of metal, which is fixed on a spindle passing across the middle of it. When the edge of this round metal plate is in the direction of the current of steam, the aperture is at its greatest extent of opening; and as the plate becomes more oblique the opening becomes less, until it is shut by the plate being at right angles to the current.

The pressure on both sides the spindle being the same, this kind of valve is opened or shut with more ease than any other; and is, therefore, very applicable here. It is not easy to make it quite steam-tight when shut, but its tightness is not of consequence in this case.

tity of steam admitted, and of course serves to make the motion less rapid.

SECTION I.

The Steam-engine Governor.—FIG. 1.

307. I K represents a spindle kept in motion by the engine;* A, B the centrifugal balls; C A and C B the rods by which the balls are suspended. These rods cross one another, and pass through the middle of the spindle at C. There is a round pin put through the spindle and the rods at C, which serves as the point of suspension for the centrifugal balls or revolving pendulum. There is a part of the spindle above C, which is square, and nicely polished, so that the piece of brass M may slide easily up and down upon it. The piece of brass M is round on the outside, and has an external groove turned upon the upper end of it to receive the lever N O, the fulcrum of

* This motion is sometimes produced by a rope and pulleys, but wheel-work being more certain, is much to be preferred.

which is at P. This piece of brass is connected with the ball-rods by two short pieces and joints D E, F G.

The construction of steam-engine governors sometimes differs a little from that now described; but if this particular construction be understood, there will be no difficulty in comprehending any other in use.

OPERATION.

308. When the engine goes too fast, the balls fly off from the spindle, and depress the end N of the lever, which partly shuts the throttle-valve, and thereby diminishes the quantity of steam admitted into the cylinder; and, on the other hand, when the engine goes too slow, the balls fall down toward the spindle, and elevate the end N of the lever, which partly opens the throttle-valve, and thereby increases the quantity of steam admitted into the cylinder.

309. This apparatus being of great prac-

tical use, and as it is applied to other purposes which I am about to describe, it may be proper here to give a rule for the number of revolutions which the spindle I K ought to make, in proportion to the situation of the balls with regard to the centre of their suspension C.

In order to explain this rule, therefore, it is proper to observe, that "there is a great analogy between the vibration of pendulums and the revolutions of balls suspended from a fixed point. If a body suspended by a thread revolve freely in a horizontal circle, the time of the revolution will be the same whenever the height of the point of suspension above the plane of revolution is the same, whatever be the length of the thread." Thus, if the balls A, B, C, Fig. 2, be made to revolve, they will arrange themselves so as to remain very nearly in the same horizontal plane. "The time of each revolution of the balls is equal to the time occupied by a double vibration of a pendulum, of which the length is equal to the height of the

point of suspension above the plane in which they revolve."*

310. Thus, for instance, if the height of the point of suspension D, Fig. 2, above the plane on which the balls revolve, be equal to the length of a pendulum which vibrates seconds, the balls, in that case, should make 30 revolutions per minute.

311. If pendulums are of the following lengths, their oscillations in one minute of time, in Britain, are as follow:

	British Feet and Inches.	Oscillations.
" Feet	0 .... Inch. 1·565	300
	0 ..... 9·782	120
	3 ..... 3·128	60
	13 ..... 0·512	30
	52 ..... 2·048	15

312. " Hence the oscillations of pendulums are in the subduplicate ratio, or as the square roots of their lengths; and the lengths of pendulums are in the duplicate

* See Young's Natural Philosophy, vol. i. p. 47.

ratio, or, as the squares of their oscillations. In order to find the length of a pendulum that will oscillate a certain number of times in a minute, make this proportion:"* as the square of the given number of oscillations is to the square of 60, or the number of seconds in a minute, so let the standard pendulum, or 39·128 inches, be to the pendulum sought.

EXAMPLE.—Required the length of a pendulum which will vibrate 20 times per minute.

$60 \times 60 = 3600$
$20 \times 20 = 400$

400 : 3600 :: F. In. F. In.
3 .. 3.128 : 29 .. 4.15

the length required.

SECTION II.

313. In a wind-mill, when the velocity is increased by the irregular action of the wind, the corn is sometimes forced rapidly through the mill without being sufficiently ground. There is an elegant contrivance for preventing this, (similar to the governor of a steam-engine,) but which I believe

* Anderson's Institutes of Physics, vol. i. p. 250.

was much earlier in use, called in some parts of England a *Lift-Tenter*. "By means of the centrifugal force of one or more balls, which fly out as soon as the velocity is augmented, and as they rise in the arc of a circle, allow the end of a lever to rise with them, while the opposite end descends with the upper millstone, and brings it a little nearer to the lower one."*

This machine is curious, and might perhaps in other cases be usefully applied. I shall, therefore, describe two constructions, but both on the same principles.

Lift-Tenters for Wind-Mills.

FIRST CONSTRUCTION.

314. This machine, and part of the stone-spindle and framing with which it is connected, are represented in Fig. 3, Plate XIII.

To the stone-spindle there are fixed four arms A, A, A, A, there are four similar arms B, B, B, B firmly attached to the hollow cylinder C, which is loose on the spindle F G.

* Young's Nat. Phil. vol. i. p. 233.

The pendulums D, D, D, D are hung above, to the arms A, A, A, A, and through holes toward their lower extremities pass the arms of the loose cylinder.

When the mill is at rest, the pendulums hang vertically; but, by their centrifugal force, when the mill is in motion they hang obliquely; and that obliquity is increased in proportion to the velocity, and proportionately raises the loose cylinder C.

This cylinder C acts on the one end of the lever E, which has a connection with the clove upon which the bridge of the stone spindle rests, and accordingly raises or depresses the upper millstone in proportion as the wind is weak or strong.

SECOND CONSTRUCTION.

315. Another modification of the same principle, (applied above the *mill-stones*,) but having one pendulum only, is represented by Fig. 4, and will be easily understood from what has been said respecting the First Construction.

These lift-tenters are drawn from sketches

which I took in the neighbourhood of Liverpool in the year 1790.

SECTION III.

316. Governors are sometimes applied to water-wheels, and made on various constructions. Smiths' bellows have been applied to that use, the upper board rising or falling in proportion to the velocity of the lower board, which received its motion from the mill. But those I am about to describe, appear to me on better principles; and as they have been found of very material use, I shall proceed to describe a construction which has for several years been at work in Cartside cotton-mill, which was erected under the direction of the late Robert Burns, Esq. (of whom Professor Robison makes respectful mention in the Encyclopædia Britannica, art. Waterworks,) and which has there given great satisfaction,* I shall afterward describe

* In a letter which I had from Mr. Burns, dated February 1808, he writes to the following effect:

"The governor is the most useful thing for a water

some other similar machines for the same use.

Water-wheel Governor.

FIRST CONSTRUCTION.

317. The principles of this kind of water-wheel governor are nearly the same as those of the governor of a steam engine. It has a revolving pendulum which receives its motion from the mill, and in proportion as the machinery moves faster or slower, the centrifugal force acts upon the governor, and raises or depresses an iron cross, which, acting on a lever, reverses the motion by the wheel work, which operates upon a sluice so as to enlarge or lessen the passage of the water to the water wheel; this sluice is made on the principles of the *throttle-valve* already described, Art. 306,

wheel that can possibly be thought of, and I wish you would adopt it in your practice wherever you desire to make your employer prosper. I am sure it is worth a large sum to us at Cartside mill, from its keeping up the speed of the machinery, and not deviating the year round."

in order that it may be moved by a small power. So long as the machinery is moving at a proper velocity, this wheel work of the sluice apparatus remains at rest.

Fig. 5 represents different views of this machine, and some of its parts detached. The same letter in all the figures refers to the same part.

The revolving pendulum E F G H receives its motion from the mill-work by means of a rope giving motion to a pulley I. The upright shaft M N is kept in constant motion by the wheel work O P R S. The wheel N acts constantly into the two bevelled wheels T and U, and makes them move in contrary directions. They are loose on the shaft when the mill is going at its proper speed.

But if the mill moves either too fast or too slow, the one of these wheels, by means of a clutch Q, in a way to be described, is connected with, and carries round, the lying shaft D C, and, by a pair of bevelled wheels, communicates motion to the oblique shaft B W; which again, by a screw X,

and quadrant wheel Y, moves the sluice Z, and, by making it stand more or less oblique, alters the area of the passage for the water.

From inspecting Fig. 5, No. 1, it will be evident that the box *a*, will be raised or depressed in proportion as the balls E and F, of the revolving pendulum E F G H, are further or nearer to the centre of motion; when the velocity is greatest, the balls E and F, by their centrifugal force, will extend themselves farthest from the centre of motion, and raise the box *a*. See also Fig. 5, No. 2, No. 3, and No. 4.

To the box *a* is fixed a cross *b c*. There is a forked lever *d q e*, the fulcrum of which is at *f*, and which turns horizontally. This forked lever has four prongs 1, 2, 3, 4.

When the mill is at its proper speed, the cross works within the prongs 1 and 2; in this situation of the forked lever, the clutch Q is disengaged from both the wheels T and U, and they move on their bushes without carrying round the lying shaft.

The clutch is made to slide on a part of the shaft which is square.

When the mill goes too quick, the cross gland is raised, and, in turning round, strikes the prong 3, which immediately causes the lever to throw the clutch into the arms of the wheel U, which then carries the clutch and shaft round with it; and by the means already described, acts on the sluice, and by lessening the quantity of water falling on the wheel, diminishes its speed.

On the other hand, when the mill goes too slow, the cross is depressed, and, striking the prong 4, reverses the motion of the shaft, and so produces a contrary effect on the sluice.

318. It may be proper to remark, that the train of wheel work is so calculated as very much to reduce the motion at the sluice, and it is found from experience that this is necessary. Were the area of the aperture too suddenly changed, the

effect on the water wheel would be too violent. Every time the mill is stopped, it is proper to lift the wheel R out of gear. The centre on which the sluice turns should be one third of its height from the bottom, in order that the pressure of the water above the centre may balance that below.

At *m* there is an upright shaft, which is worked by hand when required.

Water-wheel Governor.

SECOND CONSTRUCTION.

319. Fig. 6, represents a sluice regulator as executed in some parts of England. It differs little from that already described, only that the lying shaft A B receives its motion immediately from the mill, instead of from the axle of the revolving pendulum, as in the first construction (Art. 317.) From having so minutely described that construction, it is hoped that the attentive reader will find no difficulty in comprehending Fig. 6, from inspecting the plate.

Water-wheel Governor.

THIRD CONSTRUCTION.

320. Fig. 7, Plate XV. represents a water-wheel governor of a very simple construction, differing from the foregoing in this respect, that it communicates most part of its motion by bands and pulleys instead of wheel work. The motion is reversed by the simple means of having one of the pulleys A with an open band, and the other B with a cross band.

Observation.

It is proper to observe here, however, as was already done with regard to the governor of the steam engine, that wheel work is much to be preferred, in point of certainty, to bands and pulleys.

Water-wheel Governor.

FOURTH CONSTRUCTION.

321. This construction is represented in Figure 8. The revolving pendulum A K

L M is kept in constant motion by the water wheel.

A, A, two wheels fixed on round sockets upon the governor spindle.

B, a clutch upon a square part of the spindle, (or, what might be better, a round with a feather upon one side;) C, a gland to connect the clutch with the sliding part K, of the governor, which has a groove to receive it like that of a bayonet. (See Essay IV. Art. 282;) D, a piece of iron which prevents the gland from turning round, and for keeping it from flying off; E, a wheel working into the wheels A, A; F, an endless screw upon the same axle with the wheel E; G, a wheel upon the same axle with another screw H, which acts into the quadrant I, upon the sluice.

The operation of this ingenious apparatus, from what has been said of the other constructions, will, it is hoped, be sufficiently clear. This governor was designed by Mr. James Carmichael, millwright, now of Dundee; but it has not, that I know of, ever been put in practice.

Water-wheel Governor.

FIFTH CONSTRUCTION.

322. From the inspection of Fig. 9, and what has been already said respecting water-wheel governors, this particular construction will doubtless be easily comprehended. I need only mention that the wiper A, by means of the forked lever B D C, acts on the clutch E. The rest of the movements resemble those of the first construction (Art. 317.)

This apparatus, remarkable for its neatness and simplicity, was constructed by Mr. Hewes of Manchester.*

* A simple, and not a very expensive apparatus for equalizing the exertion of horses in thrashing machines, is described in the art. Agriculture, Supplement to Ency. Brit. p. 200; and in Brewster's edition of Ferguson's Lectures, p. 201, vol. ii. (Ed.)

APPENDIX.

ON THE

VELOCITY OF WATER WHEELS.

No. I.

On the Velocity of Water Wheels, by Mr. Robertson Buchanan, Engineer: communicated in a Letter to the Editor of the Philosophical Magazine.

London, No. 75, Picadilly,
14th of August, 1801.

DEAR SIR,

THE accompanying paper was read in May 1799, in a Philosophical Society at Edinburgh. I offer it to you with diffidence, knowing that it contains things contrary to received opinions. Having, however, made no wilful error, if you think proper to publish it in your Magazine, it

may induce those who have leisure and abilities to enter more fully into the investigation of the subject. I am, dear Sir, your very humble servant,

ROBERTSON BUCHANAN.

Mr. Tilloch.

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323. There are many cases in which it is of importance to know the proportion of power necessary to give different degrees of velocity to a mill.* But as the construction of mills, and the purposes they serve, are various, it is perhaps impossible to find any law of universal application. Mr. Banks in his *Treatise on Mills*,† has drawn a conclusion, which he appears to consider as invariable, namely, that "when a wheel acts by gravity, its ve-

* It was a scarcity of water for the Rothesay mills which directed my attention particularly to this subject.

† See Banks on Mills, p. 17, 18, 144, 145, 146.

locity will be as the cube root of the quantity of water it receives."

But if we suppose a wheel raising water by means of cranks and pumps, on Mr. Banks's principle, it might easily, I think, be demonstrated, that, by reducing the velocity of the wheel to a certain degree, the wheel would raise more water than would be necessary to move it at that velocity; a thing evidently impossible.

In this view, it would seem there is no actual case in which Mr. Banks's conclusions will hold true. But, however they may apply to other mills, the experiments which I am going to mention seem to me to prove, at least that they do not apply to cotton mills. On the ground of these experiments, made at different times, and with all the attention in my power, (and not from any abstract consideration,) have I presumed to call in question an authority for which I entertain the highest respect.

324. In January 1796 I measured the

quantity of water the old Rothesay cotton mill required: 1st, When going at its common velocity; and 2ndly, When going at half that velocity. The result was, that the last required just half the quantity of water which the first did. It is to be observed, that in these experiments the quantities of water were calculated from the heads of water and apertures of the sluices.

From these experiments I inferred, "That the quantity of water necessary to be employed in giving different degrees of velocity to a cotton mill, must be nearly as that velocity."

I was satisfied with this experiment, and the inference I drew from it, till some gentlemen well acquainted with the theory and practice of mechanics, expressed their doubts on the subject. I had then recourse to another experiment, which I considered as less liable to error than the former.

325. The water which drives the old cotton mill falls, a little below it, into a

perpendicular-sided pond, which serves as a dam for a corn mill. To ascertain, therefore, the proportional quantities of water used by the old mill, nothing more was necessary than to measure the time the water took to rise to a certain height in that pond; and accordingly, on the first of May 1798, I made the experiments noted in the following table:

1	2	3	4	Number of experiments.
46	46	24	23	Revolutions of one of the upright shafts per minute.
5	5	5	5	Rise of water in the pond in inches.
6·58	6·57	14·45	15.0	Time in minutes and seconds.

The first and second experiments were made with the mill at its common velocity; the third and fourth at nearly half that velocity.

The time which the mill required to use the same quantity of water in these experiments may be taken in round numbers; the proper velocity at 7 minutes, and half that velocity at 15 minutes.

The result of these experiments approaches very nearly to that of 1796. The

difference may be accounted for by the small degree of leakage which must have taken place at the sluices on the lower end of the pond; and the time being greater in the third and fourth experiments, the leakage would, of course, be greater.

326. Mr. Smeaton * and others have proved, in a very satisfactory manner, that "the mechanic power, that must of necessity be employed in giving different degrees of velocity to the same body, must be as the square of that velocity." But it appears to me, that the result of the above experiments may be easily reconciled to this proposition, by considering what Mr. Smeaton says immediately afterwards:— "If the converse of this proposition (says he) did not hold true, viz. That if a body in motion, in being stopped, would not produce a mechanical effect equal or proportional to the square of its velocity, or to the mechanical power employed in pro-

* See Smeaton on Mills, p. 18. See his Miscellaneous Papers, p. 92.

ducing it, the effect would not correspond with its producing cause.'* Now, it is to be observed, that Mr. Smeaton's experiments were made on the *velocity* of heavy bodies *free from friction* and *other causes of resistance;* but in mills there is not only friction, but obstacles to be removed: and experiments made on friction have proved that the frictions of many kinds of bodies increase in direct proportion to their velocity. But the velocity of a cotton mill at work may be considered as a mechanical effect; and, if so, must correspond with its producing cause.

[A. 326.] The preceding experiments on the Rothesay mill, are undoubtedly correct, and consistent with the principles of motion and power; and also with the experiments of Smeaton on Mills, and Mechanic Power.

It is shewn in the additions to this essay

* Smeaton on Mechanic Powers applied to Bodies at rest. Miscellaneous Papers, p. 92. (Ed.)

that the mechanical power is as the quantity of water on the wheel, multiplied into its velocity when the wheel, fall, and other circumstances, remain the same, (Art. [D 828.]) and since the mechanical effect is measured by the resistance multiplied into the velocity of the working point, when the friction is constant; if you diminish the quantity of water by its half, you must either take away half the resistance, or half the velocity with which it is overcome; otherwise there will not be an equilibrium between the power and effect. But at the same time it is to be observed, that an increased velocity lessens the friction of the intermediate machinery; and consequently a greater effect would be produced by the greater velocity, as appears to be the case by the experiments. There is not, however, in the detail of these experiments, sufficient data to enable us to arrive at any useful conclusions. (Ed.)

No. II.

The following Letters from Mr. John

Roberton, Engineer, contain some Valuable Observations on the foregoing Paper.

Glasgow, Oct. 21, 1799.

DEAR SIR,

327. Since I wrote you last I have further examined Mr. Banks *on Wheels*. His conclusions give a most satisfactory evidence that particular care and judgment are necessary in making experiments.

It appears to me, that the wrong conclusions which have been drawn by this and other writers on this subject, have wholly arisen from misapprehending some of Sir Isaac Newton's fundamental principles of mechanics, and from a love of establishing theoretical expressions rather than strict observations of the invariable laws of nature; expressions such as these: viz. *Quantity of Motion, Instantaneous Impulse.*

Taking a constant portion of time (viz. a second) to be the measure of the velocity of a body, and an instant to be the measure of the effect it produces; or by taking time as the measure of the cause, and space as

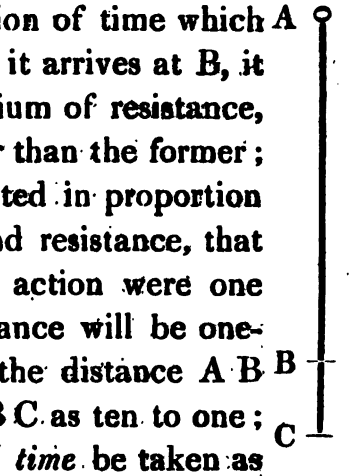
the measure of the effect. As to an *instantaneous* effect, it is an absurdity in itself as well as in mechanics. We can form no idea of a body put into motion, without the acting power or body act upon the body put into motion for some *time*, and also over some *space*; and to suppose otherwise leads us entirely out of the sound principles of mechanics.

In mechanics every effect is equal to its producing cause. In the case of a power acting on a body producing motion, and also this body acting against another power which retards its motion: if the causes of action and resistance are each measured by the *time* the motions are produced and retarded, the result will be equal.

Or if they be measured by the *space* over which they act, the results will be equal; and this is an universal principle, whether applied to accelerating power and motion, as gravity, &c. or to machines which act constantly and uniformly. Yet in the case of uniform motion, space or time may be used at pleasure; as from the uniformity

of space and time they become a common measure.

To illustrate this, suppose the body A acted upon by the power of gravity through the space A B, in a portion of time which we will call one. When it arrives at B, it meets with another medium of resistance, which is ten times greater than the former; the body A, will be resisted in proportion to the cause of action and resistance, that is to say, if the *time* of action were one second, the *time* of resistance will be one-tenth of a second, and the distance A B will be to the distance B C as ten to one; so that whether *space* or *time* be taken as the measure of action, the same must be taken for the measure of the effect, to have the results proportionate and equal. But if the cause be measured by *time*, and the effect by *space*, the results will be as the squares of the times, or, which is the same thing, as the squares of the velocity.



Thus, suppose a body in motion, with a velocity of one, has a power to penetrate into a bank of earth one foot. If the same

body, with a velocity of two, strike the bank, it will penetrate to the depth of four feet: for the velocity is double, and the time of action is double, and therefore the results will be compounded of both, that is, as the square of the velocity.

From the above it may be inferred, that if equal bodies be acted upon by unequal powers, the times requisite to produce an equal motion will be reciprocally proportionate to the powers; that is to say, if a power of ten act upon a body for one second of time, and the power of one act upon an equal for ten seconds, they will produce equal velocities. But the spaces through which the bodies are carried, are very unequal, being as ten to one: and if the square roots of the powers producing the effects be taken, that will give the times they take in carrying the body acted upon through equal spaces.

But it is obvious this doctrine has no more to do with the operation of machines, than simply their first starting from rest to the motion necessary for working. When

this is acquired, the power applied and the power of resistance balance each other, and whatever be the motion the machine moves at, the same power will carry it on, (if it be upheld) provided the machine act in such a manner as not to accumulate resistance by the accumulation of motion, which is the case in forcing fluids through pipes, &c. In cases of this kind, the nature of the machine must be particularly kept in view, and not to adopt any law to explain the resistance the acting body meets with, but what is simply deduced from the very machine we have under consideration. But in most cases, any machine may be considered as acting purely on a statical principle. The raising of weights, or overcoming friction, I consider purely as acting on that principle; and when the power of action is equal to the resisting power, the machine is indifferent to motion or rest. If the machine be at rest, the power will not move it, being a balance to the resistance. If the machine be set in motion, the power will keep it in the same motion,

Banks, at his highest motion, run his wheel about one foot in the second, and reducing it to one half of that motion, the same quantity of water then expended, was capable of performing four times the work; and by deduction from thence, it appears plain that his wheel (from his own theory) would perform about twenty times the quantity of work which Mr. Smeaton's could perform with the same quantity of water, and about 16 times more than nature; so that your observation (alluding to Mr. Banks's theory) is very just in saying that, by reducing the motion of the wheel, it is demonstrable it would raise more water than supply itself.

(Signed) JOHN ROBERTON.

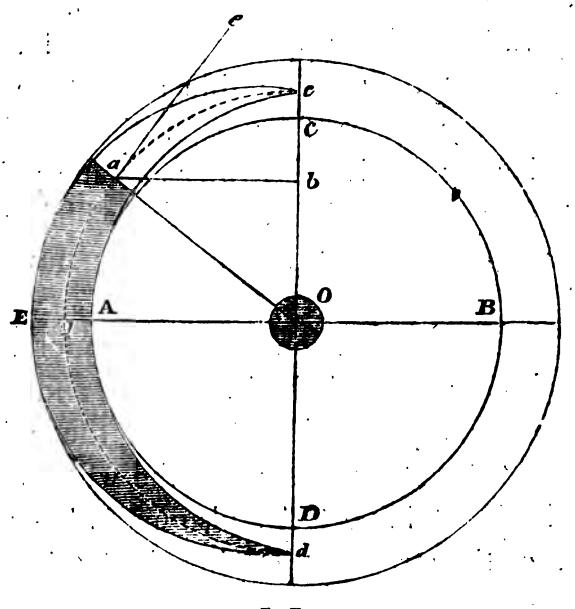
On Overshot Water Wheels.

[A. 328.] The best water wheel is that which is calculated to produce the greatest effect when it is supplied by a stream, furnishing a given quantity of water, with a given fall.

The mechanical effect depends on the

proportion of the wheel's diameter to the height of the fall; and on the velocity of the circumference of the wheel. These are the two principal parts to be considered in the theory of wheels; but there are also some other points which ought to be attended to, because the effect is much decreased when they are neglected.

Of the proportion of the radius of the wheel to the height of the fall.—Let A C B D be the wheel, and E A the depth of



L L

the buckets; then, according to experiments on water wheels, it appears that the rotary force of the water in the buckets is nothing at c and d, and that it increases nearly, if not accurately, in the direct ratio of the distance from c or d, and is greatest at A. That is, the force at any point a in a direction $c\,a$, or perpendicular to the radius, is as $a\,c$.

A slight consideration of the figure is sufficient to inform us, that the wheel will not produce the greatest effect when it receives the water at the upper point C, and that there must be considerable advantage in making the wheel of a greater diameter, so that it may receive the water at some point between A and C. The point which will ensure the greatest effect we are now to calculate.

Put c = that portion of the circumference which is to be loaded with water; and x = the arc comprehended between the point where the water flows upon the wheel and the horizontal line E A; also make b = the area of the stream supplying the buckets.

Then the solid which represents the effective force, will be $\frac{1}{4} b \times \left(\frac{c^2-2x^2}{c-x}\right)$; which is to be the greatest possible; or $\frac{c^2-2x^2}{c-x}$ = a maximum. By the principles of maxima and minima, this takes place when $x = c\,(1-\sqrt{\frac{1}{2}})$ or $x = \cdot 2929\ c$. Accordingly the arc $c-x$ must be the quadrant dg or 90°, and the arc $x = 37\cdot 27°$.

Hence we have this important practical maxim. A water wheel will produce the greatest effect when the diameter of the wheel is proportioned to the height of the fall, so that the water flows upon the wheel at a point about 52½ degrees distant from the summit of the wheel.

If r be the radius of the wheel to the extreme part of the bucket, and h the effective height of the fall, then $h = r\,(1 + \sin. 37\frac{1}{2},)$ or $h = 1\cdot 605\,r$; for the sin. $37\frac{1}{2} = \cdot 605$. Also $\cdot 623h = r$. Therefore when the effective height of the fall is determined, the radius of the wheel is easily calculated. When the effective fall is ⅓ of the whole

fall, if we make h the whole fall, $r = \cdot 554\ h$, or $1 \cdot 108\ h$ = the diameter of the wheel.

The effective height of the fall is less than the true height, by as much as is necessary for giving the water the same velocity as the wheel before it flows upon it.

In low falls a wheel would work with advantage in a considerable depth of tail water, provided the buckets were of a suitable form for moving through the water, and the effective fall made through a very accurate sweep, so that the sweep and not the form of the bucket should confine the water upon the wheel.

[B. 328.] *Of the Velocity of the circumference of the wheel to produce a maximum effect.*—It is necessary to premise, that the velocity with which the water flows upon the float-boards or buckets, is considered to be equal to the velocity of the wheel, and to strike against the floats as nearly as possible in the direction of the motion of the wheel.

Let x be that part of the fall which gives the necessary velocity v to the water, when the effect is a maximum; v will then be the velocity of the circumference of the wheel. Also, make a = that part of the fall which would correspond to the velocity of the circumference of the wheel when the power would be equal to the friction of the loaded machine only; or when the useful effect would be nothing. Now if h be the whole fall, the effective force of the water on the wheel will always be proportional to $h - x$, when the effect is a maximum; and to $h - a$, when the useful effect, or work done, is nothing.

Hence, $v\ (\overline{h - x} - \overline{h - a})$ must be a maximum; or, $v\ (a - x)$ = a max. but $v = x^{\frac{1}{2}}$, therefore $x^{\frac{1}{2}}\ (a - x)$ = a max. which according to the rules of maxima and minima takes place when $a = 3\,x$.

It is evident that the value of a must entirely depend on the nature of the machine, for if there be many moving parts between the power and the resistance, the friction will be greater, and consequently a will be

less. The machine must be very simple indeed, if the friction be less than one-half the moving power, and it will often amount to two thirds of it. If we suppose it to be two thirds, then $a = \frac{h}{3}$, and consequently $x = \frac{h}{9}$, and $v = \sqrt{\frac{64\frac{1}{2}h}{9}} = 2{\cdot}67\sqrt{h}$.

Hence when the friction amounts to two thirds of the moving power, the velocity of the circumference of an overshot wheel in feet per second, should be 2·67 times the square root of the whole height of the fall in feet.

Again, that part of the fall is to be determined, which will give the water the same velocity as the wheel, and since $a = \frac{h}{3}$, and $3x = a$, we have $x = \frac{h}{9}$. Hence, when the friction is two thirds of the power, that part of the fall which will give the water the proper velocity, is one ninth of the whole height.

These results may now be usefully compared with the experiments of Smeaton; at the same time it is obvious that his experi-

ments were not adapted for arriving at general conclusions, because the water was always delivered upon the same wheel; for it is clear, from the preceding investigation, that every particular wheel must have its particular maximum.

In Smeaton's experiments on overshot wheels, the wheel was 2 feet in diameter, therefore the height of the fall should be $2\frac{1}{4}$ feet. Now the square root of $2\frac{1}{4}$ is 1·5; and $1{\cdot}5 \times 2{\cdot}67 = 4{\cdot}005$, that is, the velocity of the wheel should be 4 feet per second; or it should make 38 turns per minute. Smeaton infers that "the best velocity for practice" will be when a wheel of 2 feet diameter makes 30 revolutions per minute. (Miscellaneous Papers, p. 51.) But his model had much more friction in proportion to the effective force of water on the wheel than two thirds, than we have here calculated upon. When the calculation is made according to the friction of Smeaton's model, $v = 2{\cdot}4\sqrt{h}$; and the velocity of the model wheel would come out 3·6 feet per second, or 34 turns per minute. This velocity will

perhaps apply correctly enough to overshot wheels, where the water flows on at the summit, and to rough made machinery; but the former calculation is that which I consider most correct, for the improved kind of wheels here pointed out. It is to be understood, that the friction allowed for, includes all the kinds of resistance and loss of force which lessen the useful effect, as well as the resistance of the rubbing surfaces, properly called friction. Many readers will think that two thirds of the effective force, is greatly too much to be lost; it will be well if it draw their attention to lessening the stress on every part of machinery, and to the importance of having few rubbing surfaces, and other causes of resistance.

[C. 328.] *On computing the power of overshot water-wheels.*—In determining the proportion of the radius of the wheel to the height of the fall, an equation is given for the effective force. See Art. [A. 328.] Resuming that equation, we have $+ b$

$\left(\frac{c^2-2x^2}{c-x}\right)$ = the effective force of the water, and $\frac{1}{4} b v \left(\frac{c^2-2x^2}{c-x}\right)$ = its mechanical power. But the quantity of water expended in maintaining this power, will be bv. Hence, the quantity of water expended, is, to its mechanical power, as $1 : \frac{1}{4}\left(\frac{c^2-2x^2}{c-x}\right)$.

When the wheel is supplied at the summit, $x = \frac{1}{4}C$; and therefore, the quantity of water expended, is to its mechanical power, as $1 : \frac{1}{4}C$. Or the power is equal to half the weight of water supplied to the wheel.

The same relation takes place when $x = o$; that is, when the wheel is supplied at the height of the axis. Hence when the radius of a breast wheel is equal to the effective height of the fall, its power will be the same as that of an overshot wheel supplied at the summit.

When the wheel is supplied at the point which produces the greatest effect, $x = .2929\,c$; and consequently the quantity of water expended is to its mechanical power

as 1 : 0·5857 c. This effect is greater than when the wheel is supplied at the summit in the ratio of 1·1714 : 1.

These comparisons will convey some useful information to many readers; and they may sometimes suggest to scientific writers the advantage of studying the actual nature of machines; for relations so extremely obvious and simple could never have been overlooked by any one who might have condescended to examine the subject.

The power of a water wheel may be considered under two points of view; each of which has its peculiar use. If we wish to compare it with any other first mover, then we shall have to calculate its mechanical power. But when it is desirable to compute the resistance it will overcome at the working point, the effective force should be calculated.

[D. 328.] When the water flows upon the wheel, either at or above the axis, the mechanical power is $\frac{1}{2} b v \frac{c^2 - 2x^2}{c - x}$ cubic feet of

water, (Art. [A. 328.]) or $31{\cdot}25\, b\, v \frac{c^2-2x^2}{c-x}$ lbs. Where $b\, v$ is the quantity of water expended in a second, in cubic feet, c the part of the circumference between the lowest point of the wheel, and the place where the water flows upon it in feet, and x the part of the circumference between the point which is level with the axis, and that where the water flows upon the wheel in feet.

Throughout these Essays, the mechanical power of a horse is estimated at 200 lbs. moving with a velocity of $3\frac{1}{2}$ feet per second. Then a water wheel will be equal to $\frac{31{\cdot}25\, b\, v\, (c^2-2x^2)}{200\times 3\frac{1}{2}(c-x)}$ horses; $= \frac{{\cdot}00426\, b\, v\, (c^2-2x^2)}{c-x}$ horses.

When the water flows on either at the summit or at the level of the axis, the mechanical power is $31{\cdot}25\, b\, v\, c$ lbs. or it is $= 0{\cdot}00426\, b\, v\, c$ horses.

When the water flows on at $52\frac{1}{2}$ degrees distant from the summit, the mechanical power is $37{\cdot}192\, b\, v\, c$ lbs. or $= {\cdot}005\, b\, v\, c$ horses. Since in this case, $c = 127\frac{1}{2}$ degrees of the circumference, we have $c =$

127½ × ·0174533 r; and as $r = ·554\,h$; and $v = 2·67\,\sqrt{h}$; by substituting these quantities, we have $122·176\,b\,h^{\frac{3}{2}}$ lbs. = the mechanical power; or $·0164\,b\,h^{\frac{3}{2}}$ = the number of horses, where h = the whole height of the fall in feet, and b the area of the aperture through which the water flows upon the wheel in feet.

[E. 328.] The effective force is $31·25\,b\,c$ lbs. when the water flows on either at the summit, or at the level of the axis.

When the water flows on at 52½ degrees distant from the summit of the wheel, the effective force is $37·192\,b\,c$ lbs. or $45·746\,b\,h$ lbs.

Of the Power of Breast Wheels.

[F. 328.] When the water flows on below the level of the axis of the wheel it may be termed a breast wheel.

Let y be the distance below the axis measured on the circumference, then $\frac{c^2 b\,v}{2\,(c+y)}$ equal the mechanical power in cubic feet

of water, or $\frac{31{\cdot}25\,c^2bv}{c+y}$ lbs. When $y = c$ the power will be reduced one half, and when $y = 2c$ it will be reduced two thirds, and so on.

If we assume that the mechanical power of an undershot wheel is half that of an overshot one "under the same circumstances of quantity and fall;"* then it will be an advantage to employ an undershot wheel whenever the fall is less than three tenths of the radius of the wheel. But since the radius of the wheel may in many cases be diminished, it does not appear to be desirable to employ an undershot wheel in any case, except where the quantity of water is great and the fall inconsiderable.

The theory of undershot wheels I do not intend to develope in this place; chiefly on account of having exceeded the bounds within which it was proposed to limit the additions to this work. Enough has been done to illustrate the view I have taken of

* Smeaton's Experiments, Miscellaneous Papers, p. 49.

the nature of mechanical power; and its application to undershot wheels and windmills, will not be difficult to any one that has acquired much information on such subjects.

ON

CHANGING

THE VELOCITY OF MACHINERY WHILE IN MOTION.

ESSAY VI.

PREFACE.

THE machinery employed in manufactures may be divided into two classes: 1*st*, Mill-Work. 2*nd*, Smaller Machinery. The mechanism described in this Essay belongs to the latter class, and has hitherto been chiefly used in Cotton mills; but useful hints may perhaps be taken for its application to other valuable purposes.

It would be satisfactory to be able to record the names of the inventors of many of the in-

genious contrivances which are described in these Essays. But the secrecy which interest prompts in the machinery used in manufactures — the same difficulties giving rise in different minds, without any communication of ideas, to the same means of overcoming them, and the very gradual steps by which improvements are usually made, render it, in most cases, impracticable to trace the inventions to their true sources.

ON

CHANGING THE VELOCITY

OF MACHINERY, &c.

INTRODUCTION.

329. I TAKE it for granted that the reader is acquainted with the common modes of altering the velocity of any particular part of machinery, by changing the wheels or pulleys. This change, however, requires that the machinery be stopped for some time until the alteration be made.

But many cases occur in which it is desirable to change the velocity without such loss of time. Some of those cases I shall now consider, beginning with one of the most simple,—that of changing the

speed of a turning-lathe, according as the nature of the substance to be turned, or its diameter may require.

SECTION I.

I. *Turning Lathe Motions.*

330. A series of pulleys gradually increasing in size upon an axle, is moved by the mill, and on the spindle of the lathe is a similar series, but in an opposite order, so that the same length of belt will work on all the opposite pulleys, according to the speed required.

These series resemble two truncated cones, having the smaller diameter of the one opposite the greater diameter of the other, so that the same belt is equally tight on whatever pair of pulleys it may work.

This contrivance is represented by Fig. 1, Plate XVI. applied to the spindle A B of a turning-lathe. C D is part of a shaft driven by the mill at a certain regular velocity. When a slow motion is required, the belt works at E F.; when a greater velocity is required, the belt is shifted by pressing it

to one side, to another pair of opposite pulleys. It is hoped that the figure will make this so clear, that all further explanation will be unnecessary.

Observation.

331. This contrivance, very simple in its construction, is found of important practical use in the turning of various substances.

II. *Alternate Cones.*

332. There is another contrivance on similar principles to that above described, which has been found very useful where a motion constantly varying is required. Instead of the opposite series of pulleys, there are two opposite cones.

The one of these cones gives motion to the other by a belt which by the machinery is gradually moved from one end toward the other of the cones.

This piece of machinery is represented by Fig. 2. A B is the belt; C is the guide, which, receiving its motion from the ma-

chinery, traverses the belt at pleasure, with any velocity which the case may require.

Thus the one cone moving at a uniform motion, communicates a varying velocity to the other.

Observation.

333. This piece of mechanism, remarkable for its simplicity, I have had occasion to put extensively in practice, and have found it give great satisfaction.

III. *Alteration of Velocity by Wheels moving one another by Friction.*

334. The same effect as the alternate cones is sometimes produced by the rim of one wheel moving on the face of another, by means of the roughness of their surfaces, the inequalities of which may be considered as indefinitely small teeth.

Thus is A B, Fig. 3, a face-wheel, moving at a uniform rate.

C D is another wheel, which, from the face of A B, receives a vertical motion.

Accordingly as it is required to move C D slower or faster, it is by proper contrivances made to act nearer or further from the centre of A B.

Observations.

335. As there must a twisting motion, similar to that of edge-stones for bruising various substances, take place here, and as it is only properly applicable to cases in which the strain is exceedingly small, I apprehend that the alternate cones is a much more perfect manner of producing a change of velocity. These wheels, however, work very well for regulating the taking up motions of the bobbins in machines for roving cotton by spindles. In this case, the force required is very small.

SECTION II.

336. Certain cases in practice require an instantaneous change of velocity; as, for instance, when those machines for spinning cotton, called *Mules*, are moved by power.

The *mule* is a machine different in its construction from that brought to a high state of perfection by Sir R. Arkwright.

The mule is better adapted than the *water-twist frame* (Arkwright's Machine) for spinning all kinds of *weft*, and produces finer yarn than can be spun by any other machine. For the invention of the *mule* we are indebted to Mr. James Crompton, formerly of Hall-in-the-Wood, near Bolton-le-Moor, Lancashire. This machine was for many years worked by hand only, the variety of its movements rendering it difficult to accomplish the moving of it by power of water or of steam sufficiently simple to be of common use.

Mr. William Kelly at Lanark, early obtained a patent for a mode of working this machine by power, but it was not until a considerable time afterward that power was generally adopted. The plans which were tried were very various, and the improvement was progressive. One happy consequence of this improvement has been experienced; the spinners are now found to

enjoy better health than they did when they had to labour hard, while they breathed in warm and confined apartments.

In order to save time after the carriage of the mule is brought to its furthest extent, it is necessary to increase the velocity of the spindles. This increase of velocity is called the *double speed*. Various contrivances have been adopted for this purpose, but I shall describe three; one being performed by *ropes*, another by *belts*, the third employing the aid of *wheels*. This last, indeed, from its greater certainty, is what is most generally adopted. These contrivances will, however, serve to shew the progress of improvement in this species of machinery.

Double Speed.

FIRST CONSTRUCTION.

337. The axle A B, Fig. 4, Plate XVII. is suspended by a cast-iron frame from the ceiling of the room. This axle is kept in motion by means of the fixed pulley C, which is moved by a belt from the mill-work. On

the same axle are two loose pulleys D and E. (Essay IV. Art. 280.) Ropes from these pulleys communicate with the fast-pulleys F and G, on the axle X Y of the fly wheel of the mule.

The loose pulleys have catches on their sides; while these are disengaged the mule is at rest. In order to put the mule in motion, the smaller pulley E, by means of the sliding guide I K L, is slipped to one side, so as to lay hold of the gland H, which is fixed on the axle, and carries the pulley round along with it, and thus moves the mule at its slower motion.

When the fly wheel W has made a sufficient number of revolutions at this rate, the slider is moved by means of wheel-work and a wiper toward the fast pulley A, which motion disengages the small pulley from the gland, and engages the larger pulley with C, which produces a quick motion in the fly wheel.

Observations.

338. This apparatus was in use in Man-

chester in the year 1797, but the shocks produced by the catches (Essay IV. Art. 281.) and other imperfections, soon occasioned its disuse. But there is often much to be learnt from the examination of machines which have been abandoned. It is but by comparison of things of the same species that we are able to appreciate their true value.

Double Speed.

SECOND CONSTRUCTION.

339. This apparatus differs from the First Construction, principally in having belts instead of ropes for communicating motion.

On the axle A B, there are five pulleys E, D, C, G, H, all of them loose but C, which is fast. When the belt from the mill-work is on C, the mule is at rest, because the axle revolves without carrying round any of the loose pulleys.

In order to put the mule in motion, the belt is, by means of a sliding guide, shifted on to the pulley D, which carries round

the pulley E along with it; and by another belt, moves the pulley F on the fly-wheel axle X Y, and thus moves the mule at its slower motion; afterward (as was described of the *First Construction*) the sliding guide shifts the belt from D to G, which, by carrying round H in a similar manner, produces a quick motion in the fly wheel W.

Observations.

340. This construction was in use in Manchester in the year 1799; and as the *shocks* complained of in the *First Construction* did not occur in this, it was found a material step in the improvement of working mules by power.

Double Speed.

THIRD CONSTRUCTION.

341. This construction differs from the *second*, in having the whole apparatus attached to the framing of the mule, and in having the aid of toothed wheels for producing the change of velocity.

On the axle A B, Fig. 6, are three pul-

leys C, D, E. The pulley C is fast on the axle. D and E are loose, but on the side of E is fixed the small spur-wheel F. The larger spur-wheel G is fast on the axle A B.

On the axle X Y are fixed other two spur wheels, H and I, of the same size as those on the axle A B, but placed so as that the larger wheel on the one axle shall be constantly in gear with the smaller on the other.

When the belt (put in motion by the mill work) is on D, the mule is at rest; when shifted on to E it carries the smaller wheel F round with it, which being *in gear* with the larger wheel H, moves the fly-wheel axle X Y at its slower motion.

On the other hand, when the belt is shifted to the pulley C, which is fast on the axle, it carries round the larger wheel G, which is also fast. G being *in gear* with the smaller wheel I, moves the fly wheel at the greater velocity, or, as it is termed, at *double speed.*

Observations.

342. This piece of mechanism was first adopted in Manchester about the year 1800, and although sometimes its parts may be somewhat differently arranged, it continues, I believe, still in general use.

While it is free from the *shocks* produced by catches, it is also (owing to having the change of velocity produced by wheels) free from the uncertainties of motion arising from any change in the tightness of the belts as employed in the *Second Construction.*

ON THE

FRAMING OF MILL WORK.

ESSAY VII.

PREFACE.

THE preceding Essays relate principally to the *moving-parts* of machinery, but as it seemed essential to a system of mill-work, to say somewhat on the subject of the *framing* which supports the moving parts, I was induced to commit to paper the following ideas on that head.

The subject might have been extended to a much greater length, and many more examples might have been given, but as this part of mill-work is at present undergoing a peculiarly rapid change, both in the materials employed, and in

the forms adopted in its construction, it is deemed unnecessary to enter further into detail.

Much of what is said in Essay II. on the strength, stress, and proportion of shafts being applicable to the proportion of various parts of framing, in order to save repetition, I refer the reader to what is there said.

ON THE

FRAMING OF MILL WORK.

SECTION I.

343. The general principles of carpentry must obviously be applicable to the framing of mill work. These principles I shall not here repeat, but beg leave to refer to what Professor Robison has written on this subject, in the Encyclopædia Britannica, and to Mr. Peter Nicholson's various writings on the subject, I shall here consider only the peculiarities of the framing of mill work.*

* See also art. Carpentry, New Supplement to the Encyclopædia Britannica. Tredgold's Elementary Principles of Carpentry, 4to. 1820; and Practical Essay on Cast Iron, 8vo. 1822. (Ed.)

344. Mill-work, from its motion, occasions a tremor on all the parts of its framing, which subjects it to much more speedy decay than the mere pressure upon carpentry.

Besides this general tremor, it is often subjected to violent sudden thrusts, from the bad action of the wheels, or from reciprocating motions.

It ought, therefore, not only to be sufficiently *strong* and *stiff*, but sufficiently *heavy*, to give solidity and steadiness.

Where the framing of machinery is not firm and well bound, a vibratory motion in its parts, of course, takes place; which vibratory motion expends a considerable portion of the power applied. This loss of power is very difficult of investigation. It is certain, however, that whatever motion of a vibratory nature is communicated to the framing and objects in contact with it, (abstracting from the elasticity of the parts,) must be lost to the effect the machine would produce, were the parts sufficiently strong and well bound together; and it is

to be observed, that firm and well-bound framing is much preferable to heavy framing not so well connected in its parts. It is as certain, that though the framing in either case may be constructed so as to be equally strong; yet the heavy framing, from its vibration, will expend more of the original power than that which is less heavy but firmly connected.

345. Besides *strength*, *stiffness*, and *solidity*, the framing of mill work requires to be constructed so as *to be easy of repair;* and so contrived, that *any particular part may be repaired or renewed* with the least possible derangement to the other parts of the framing.

346. There is another circumstance in this species of framing which demands great attention. *The shafts often require to be restored to their true situations*, from which they may have deviated by the wearing of the parts. Now the framing ought to be so constructed as easily to admit of

this *restoration of the shafts*, as also of any other shifting of them which may in practice become necessary.

[A. 346.] But though the framing which supports the parts of mills and machines should be firm, it is an advantage that the part on which any axis rests should have a small degree of elastic tremor when the machine is in motion. Such tremor has considerable power in diminishing the friction. It may further be observed, that framing to support machinery should be as independent of the building as possible, because the tremor it always communicates is exceedingly injurious. (Ed.)

Before proceeding further into the subject, it may be proper to consider the *bearings* of shafts.

SECTION II.

Of the Bearings of Shafts.

347. The bearings on which gudgeons and journals rest and revolve, are sometimes

termed *Pillows*, and frequently *Brasses*, from being often made of that substance.

The *bearings* for pivots, at the lower extremity of upright shafts, are denominated *Steps;* the parts where the journals of vertical shafts or spindles turn and bear against, are called *Bushes;* and for small spindles, such as those used in the manufactures of flax and cotton, *Breasts.*

It has become general to fix pillows in blocks of cast iron. Hence the term *Pillow Block*, and sometimes, corruptly, *Plumber Block.* In Manchester they are called *Pedestals.*

348. The SUBSTANCES used for *Pillows*, &c. are various, but brass is the most common.* Other substances, however, which are cheaper, have in many instances been found equal, at least, in durability.

* The metal our author terms brass, is usually the composition of copper and tin, called gun metal. Gun metal is much harder than common brass, and much more durable. Common brass is a compound of copper and zinc, and is now rarely used for bearings. See Art. [B. 207.] (Ed.)

At the cotton works of Deanston, near Down, a water wheel has run nearly 30 years on pillows of cast iron, with little sensible wear on the gudgeons, nor were they ever found liable to heat.*

The outer skin of cast iron, particularly when cast in metallic moulds, is remarkably hard, and it is reasonable to suppose that it would make a durable pillow, as we have seen is the case in the above instance.

Mr. Murray of Leeds has found a way of boring the hardest cast iron. He shewed me some cylinders of it, which, from the whiteness of the grain at the places broken

* It is very common to run water on the gudgeons of water wheels, to prevent them from heating. I doubt much of the propriety of this practice. Bees' wax has been found perfectly effectual for preventing journals from heating.

Heating, in these cases, takes place often from the gudgeons not being firmly fixed in the shaft, or from a vibratory motion in the shaft itself; it sometimes takes place from the surface of the journal and pillow being too small, and sometimes from the journal having worn too deep into the pillow, in which last case, in particular, a great friction takes place.

off by a chisel, denoted its quality. Such iron is equally hard throughout.

He mentioned that a patent was granted for wheel bushes of metal, of a peculiar hardness, which metal is nothing more than very hard cast-iron, but the patentee had discovered a mode of boring it.

Stone has often been used with good effect for pillows for gudgeons and journals. The great objection to stones for this purpose, is the difficulty, arising from their hardness, of forming them into proper shapes.

At Sheffield, where the journeymen grinders are obliged to keep this part of their machinery in oil, and in repair, they have found, from long experience, that a piece of green (unseasoned) thorn-tree is exceedingly durable.* But in general they prefer using brown paper, adding always one ply sometime after another, so as to form a kind of pasteboard; this substance

* Green oak soaked in boiling oil, is said to be used with advantage. Brewster's Additions to Ferguson, vol. ii. p. 179. (Ed.)

they find less liable to heat, and much more durable than brass.*

Wooden pillows are often used. Box-wood and lignum vitæ were long in use. The latter has been found an improper substance for the purpose. Beech is preferable to either, and has been used with great success for steps. Holly has also been found to answer well for the same purpose.†

* If the bearings for gudgeons were made by screwing many thicknesses of pasteboard together, in the same manner as the rollers of calenders are made, they would be extremely durable and have very little friction. (Ed.)

† Friction rollers are sometimes employed to diminish the quantity of friction; but not with much advantage in heavy machinery, because they are liable to get out of order, and require very accurate workmanship. Their effect depends on converting a sliding into a rolling motion; with only the slide of the small axis which retains the roller in its place. Friction wheels are also used for the same purpose; they differ from rollers in this—the stress on the axis is borne by the axes of the friction wheels; but the stress is on the surfaces of the rollers. The advantage of friction wheels is very trifling. (Ed.)

Form of Steps.

349. While on this part of the subject, I may mention some of the FORMS of Pivots of Upright Shafts.

The most usual form is to terminate vertical shafts somewhat like an egg, leaving the pivot rather smaller upwards, to prevent it from binding in the step. (Plate XVIII. Fig. 1.)

350. Another mode (see Fig. 2.) is to terminate the shaft flat at the lower end, and make a small oblong recess in it. To this end is fitted a round piece of steel A, flat below, excepting a groove *a* across it, something like that in the head of a screw nail. The use of the groove is regularly to feed in the oil. The step into which the pivot works, is made square or octagon, so as to supply oil from the angles. No. 2, 3, and 4, Fig. 2, are different views of the piece of steel A.

351. A pivot and step on this construc-

tion was deposited with the Society for the Improvement of Arts, and was said to have been 20 years in use in a horse mill, without being perceptibly worn. I had occasion, many years ago, to apply this contrivance in a case of heavy upright shafts, where other means were found inadequate to prevent the action of the pivot, and it has ever since given satisfaction in its use. It is to be observed, however, that it does not answer well in cases having much lateral pressure, and a better mode (see Fig. 3.) is now in use in several mills. The steel pivot is made cylindrical, and fixed into the foot of the upright shaft. The bottom of the step is convex, and there is interposed one or more pieces of steel formed like a double convex lens. These pieces of steel having a little motion, make the relative motion of the pivot less, and consequently lessen the friction.

352. The egg-formed pivot is sometimes made separate, of wrought iron and steel,

and inserted into the lower end of the cast-iron shaft.*

353. Mr. Bramah, in the specification of his patent machinery for surface planing, includes a mode of running pivots entirely on a fluid, and raising or depressing them at pleasure, by means of a small forcing-pump and stop cock. See Gregory's Mechanics, vol. ii. p. 418, 2nd edit.

354. The journals of upright shafts are supported sometimes by breasts, (Fig. 4.) and sometimes by bushes, in passing through a floor.

355. The spindles of mill stones usually run in wooden bushes. A block of cross

* The rubbing surfaces of cast-iron pivots, should not have a greater pressure upon them than one ton upon a square inch, or they will be very subject to heat, and the friction and wear will be increased. Large vertical shafts may often be made to revolve on conical rollers, on the same principle as friction rollers; when they are well made the motion is very smooth, and the friction much reduced. (Ed.)

elm A B C, Fig. 5, about 9 inches diameter, and 3 inches thick, forms the principal part of it, and is lodged in the eye of the mill stone. In order that the spindle may at all times run steadily, there are three pieces of hard wood D, D, D, let into grooves in the block, so that their three ends embrace the spindle E. These pieces are of equal breadth throughout, so that they may easily be wedged forward when they wear. This simple and ingenious contrivance has been very long in use. Some use a piece of cast iron in preference to the block of elm, to answer the same purpose, and some a greased rope to run the spindle in, instead of the three pieces of wood.

SECTION III.

Of Wooden Framing.

HEADSTOCK FRAMING.

356. The framing used for supporting the gudgeons of a water wheel is denominated the head-stock framing.

A, Fig. 6, represents the head-stock,

which contains the pillow-block, B C D E is the frame.

The frame is supported by the top of the building of the arch or wheel-pit.

The head-stock rests on the frame, and is moveable horizontally on all sides; when in its proper situation, it is kept there by a key or wedge G at each end of the head-stock, which is supported by the dovetail form of the lower part of the head-stock.

FRAMING FOR LYING SHAFTS.

357. Lying shafts are usually supported by bridges between posts. A B, Fig. 7, represents part of lying shafts, C D the bridge which carries the shaft. It is raised or lowered by means of a key below, and another above it, in the mortice of the posts E G and H I, through which it passes.

The bridge is also moveable on end, and is kept in its proper situation by means of small keys K, K, K, K.

358. The posts, instead of being each

made of one solid piece of timber, are sometimes framed of separate pieces, as represented in Fig. 8.

Lying shafts, instead of being supported by posts, are sometimes suspended from a ceiling, as shewn in Fig. 9. The bridge is tempered by keys, &c. as when posts are used.

FRAMING FOR UPRIGHT SHAFTS.

359. Upright shafts are generally supported by bridges adjusted endwise, and upward and downward, like those of the lying shaft; but in order that they may be moved horizontally in every direction, the pedestal is contrived to receive keys at its ends, similar to a head-stock. (See Fig. 10.)

Screws are frequently used instead of wedges for adjusting the step.

360. Fig. 11 represents the framing of an upright and lying shaft connected by bevelled wheels.

361. Sometimes a bridge is not imme-

diately supported by posts, but by intermediate pieces, which are called *cloves*. This construction is common in single corn-mills. Thus A B, Fig. 12, is a bridge; C D and E F are cloves.

362. Respecting the decay of timber, and the means of preventing it, I beg leave to refer to Dr. Parry's paper, in the Transactions of the Bath Agricultural Society, and reprinted in Nicholson's Journal, Vol. XX. Nos. 85, 86, 87, and Repertory, No. LXIII. That paper appears to me well worthy the attention of those who have occasion to construct works of timber.*

SECTION IV.

Of Cast-iron Framing.

363. In the Introduction to Essay II. *on the Shafts of Mills, &c.* I mentioned the great increase of late years of the use of cast iron in mill-work.

* See also "Elementary Principles of Carpentry," Sect. X. Art. 327—365. (Ed.)

Cast iron possesses great superiority over timber, for constructing the framing of mill-work. It is not only much more durable, but from the uniformity of its texture, may be converted into any shape, so as to give it great advantage in arranging the materials with respect to strength, and proportioning it to the stress it has to sustain. Timber, on the other hand, being stronger in some directions than others, and of very limited breadth, is confined in its arrangement, and requires, in certain cases, much workmanship; whereas, after the patterns for cast iron are once made, any number of castings may be formed from them with very little labour or trouble.

Those who have scientifically considered the strength and stress of materials, know that when timber is broken by any lateral pressure,* it is owing in a considerable

* See Emerson's Mechanics, Sect. VIII. p. 93, and Gregory's Mechanics, Vol. I. Book I. Chap. V.

These references must have been made without consulting the works quoted, as the investigation of the

degree to the compression of the beam on the hollow side, which puts the fulcrum of the ideal lever much nearer the point of resistance than it would be in a substance less liable to compression. Cast iron is much less liable to compression than timber, which gives it an advantage in withstanding lateral pressure, greater than might be expected from the mere comparative absolute cohesion of the substances.*

364. "Iron is generally much more

strength of beams is conducted by both these writers on the supposition, that the virtual fulcrum is an incompressible arris at one of the surfaces of a beam; and the one considers the materials to be extensible, the other inextensible. (Ed.)

* The idea that the virtual fulcrum is nearer the compressed side in cast iron than in wood, when the pieces are similarly strained, is at best an assertion without a proof, either from theory or experience. And at the time our author wrote, the resistance of cast iron to compression was greatly overrated. See Essay on Cast Iron, art. 63. (Ed.)

"uniform in its strength than wood; yet "experiments shew that there is some dif- "ference occasioned by different kinds of "ore: the difference is not only found in "iron from different furnaces, but from "the same furnace and the same melting; "this may arise in a great measure from "the different degrees of heat which it has "when it is poured into the mould."*

365. Mr. Banks concludes that a bar of the weakest cast-iron, 1 inch square, and 1 foot long, will break with about 2190 lbs. and that cast iron is at an average 4 times as strong as *oak*, and 5¼ times as strong as *deal;* the weight being in all cases applied in the middle; the beam lying horizontally, and supported by props.†

366. The strength of any beam, to withstand any weight, being as the breadth and the square of the depth, (see Essay II.

* Gregory's Mechanics, vol. i. Art. A. 190.

† Banks on Power of Machines, &c. p. 94.

on the Shafts of Mills, &c. chap. iv. Emerson, p. 93.) it is evident that a bar of cast iron of the same length, must be much stonger when its transverse section is like Fig. 14, than when like Fig. 13. The form represented in Fig. 14. has a further advantage, that of greater *stiffness*. The distinction between *strength* and *stiffness* is not in practice generally understood or attended to. This distinction is most easily comprehended by considering their limits. The limit of *strength*, is well known to be *fracture*, or breaking. The limit of stiffness, is *flexure*, or bending. Now stiffness increases in a much higher ratio than strength, viz. as the cube of the depth.* For example, if we double thedepth of a beam, we increase its stress only 4 times, whereas we increase its stiffness 8 times. See Essay II. on the Shafts of Mills, Art. 173, and 174.)

367. For these reasons, the advantage

* Young's Nat. Phil. vol. ii, art. 333.

is evident of making cast-iron framing in thin broad plates, at right angles to one another, instead of imitating the solid forms of wooden framing. This practice is called by mill-wrights *feathering*. The plate is sometimes on one side, as represented in Fig. 15, and sometimes its section is like the letter T, see Fig. 14, the whole being one solid mass.

The common practice in making cast-iron framing now, is to imitate wooden framing, which has been found from experience sufficiently strong in giving the same breadth and depth of the several pieces at their point of greatest stress. Thus, suppose Fig. 16. to be the section of the timber at the place of greatest stress, the section of the cast iron is made like Fig. 17, or like Fig. 18; advantage is also taken of the nature of the material, to give it a breadth varying in proportion to the stress. This variation in shape is not always in practice judiciously done; by attending to what is said in Essay II. Chap. IV. the mill-wright it is hoped, will be bet-

ter enabled to proportion the parts to the stress they have to sustain.* I also take leave to refer to what is said respecting the making of patterns in the appendix of Essay I. on the Teeth of Wheels, Art. 104, 108. I may add to what is there said, that it is a good practice to give the patterns a thin coat of oil paint; as, while it preserves the pattern, the paint makes it rise more freely out of the sand.

368. To give an instance of this variation of form in the framing of mill work, bridges of wood for sustaining the shafts are usually made as represented in Fig. 19, those of cast iron as shewn in Fig. 20.

369. In cast-iron framing, advantage is

* The most advantageous forms for different purposes, have been considered in my *Practical Essay on Cast Iron*, Sect. III. and IV. where extensive tables of the strength and stiffness of cast iron will be found, which may frequently save the mill-wright much trouble in calculation; for he cannot always have examples of the same construction to refer to, either executed in wood or iron. (Ed.)

also taken of the properties of the hollow cylinder, of the economical application of which form in nature we have so many beautiful examples. (See Essay II. Art. 179.)

370. A head stock of cast iron for a water wheel is represented in Fig. 21. Plate XIX.

371. Various modes are used of suspending shafts from a ceiling. Fig. 22, represents a construction in very general practice.

372. I shall conclude with referring to Fig. 23, which represents the cast-iron framing of a flour mill having three pair of mill stones, and to Fig. 24, a machine used in bleaching, called *Squeezers.*

After the process of washing by the dash wheel, the water is compressed from the cloth by means of this machine.

Squeezers consist of a pair of wooden rollers, which, in moving, draw the cloth

through between them. The lowef roller receives its motion from a mill, and the uppermost is pressed down upon it by means of levers. Till of late these rollers were fixed in strong wooden frames; but the framing is now generally made of cast-iron, which makes a neater and more durable piece of work.

A represents the lower roller, B the upper roller, C D a lever which presses upon the brass of the upper roller, E F another lever to increase the power connected with C D. The extremity of F is kept down by a pin; in some cases a weight is used in place of the pin.

373. I hope some tables which I have annexed respecting the strength of several substances, will be acceptable to the reader; the table of squares and cubes, as also the square roots and cube roots of all numbers from one to 1000, which I have taken the liberty to extract from Dr. Hutton's "Course of Mathematics," will be found very useful on many occasions.

Number.	Square.	Cube.	Square Root.	Cube Root.
1	1	1	1·0000000	1·000000
2	4	8	1·4142136	1·259921
3	9	27	1·7320508	1·442250
4	16	64	2·0000000	1·587401
5	25	125	2·2360680	1·709976
6	36	216	2·4494897	1·817121
7	49	343	2·6457513	1·912931
8	64	512	2·8284271	2·000000
9	81	729	3·0000000	2·080084
10	100	1000	3·1622777	2·154435
11	121	1331	3·3166248	2·223980
12	144	1728	3·4641016	2·289428
13	169	2197	3·6055513	2·351335
14	196	2744	3·7416574	2·410142
15	225	3375	3·8729833	2·466212
16	256	4096	4·0000000	2·519842
17	289	4913	4·1231056	2·571282
18	324	5832	4·2426407	2·620741
19	361	6859	4·3588989	2·668402
20	400	8000	4·4721360	2·714418
21	441	9261	4·5825757	2·758923
22	484	10648	4·6904158	2·802039
23	529	12167	4·7958315	2·843867
24	576	13824	4·8989795	2·884499
25	625	15625	5·0000000	2·924018
26	676	17576	5·0990195	2·962496
27	729	19683	5·1961524	3·000000
28	784	21952	5·2915026	3·036589
29	841	24389	5·3851648	3·072317
30	900	27000	5·4772256	3·107232
31	961	29791	5·5677644	3·141381
32	1024	32768	5·6568542	3·174802
33	1089	35937	5·7445626	3·207534
34	1156	39304	5·8309519	3·239612
35	1225	42875	5·9160798	3·271066
36	1296	46656	6·0000000	3·301927
37	1369	50653	6·0827625	3·332222
38	1444	54872	6·1644140	3·361975
39	1521	59319	6·2449980	3·391211
40	1600	64000	6·3245553	3·419952
41	1681	68921	6·4031242	3·448217
42	1764	74088	6·4807407	3·476027
43	1849	79507	6·5574385	3·503398
44	1936	85184	6·6332496	3·530348
45	2025	91125	6·7082039	3·556893

Number.	Square.	Cube.	Square Root.	Cube Root.
46	2116	97336	6·7823300	3·583048
47	2209	103823	6·8556546	3·608826
48	2304	110592	6·9282032	3·634241
49	2401	117649	7 0000000	3 659306
50	2500	125000	7·0710678	3·684031
51	2601	132651	7·1414284	3·708430
52	2704	140608	7·2111026	3·732511
53	2809	148877	7·2801099	3·756286
54	2916	157464	7·3484692	3·779763
55	3025	166375	7·4161985	3·802953
56	3136	175616	7·4833148	3·825862
57	3249	185193	7·5498344	3·848501
58	3364	195112	7·6157731	3·870877
59	3481	205379	7·6811457	3·892996
60	3600	216000	7·7459667	3·914867
61	3721	226981	7·8102497	3·936497
62	3844	238328	7·8740079	3·957892
63	3969	250047	7·9372539	3·979057
64	4096	262144	8·0000000	4·000000
65	4225	274625	8·0622577	4·020726
66	4356	287496	8·1240384	4 041240
67	4489	300763	8·1853528	4·061548
68	4624	314432	8·2462113	4·081656
69	4761	328509	8·3066239	4·101566
70	4900	343000	8·3666003	4·121285
71	5041	357911	8·4261498	4·140818
72	5184	373248	8·4852814	4·160168
73	5329	389017	8·5440037	4·179339
74	5476	405224	8·6023253	4·195336
75	5625	421875	8·6602540	4·217163
76	5776	438976	8·7177979	4·235824
77	5929	456533	8·7749644	4·254321
78	6084	474552	8·8317609	4·272659
79	6241	493039	8·8881944	4·290841
80	6400	512000	8·9442719	4·308870
81	6561	531441	9·0000000	4 326749
82	6724	551368	9·0553851	4·344481
83	6889	571787	9·1104336	4·362071
84	7056	592704	9·1651514	4·379519
85	7225	614125	9·2195445	4·396830
86	7396	636056	9·2736185	4·414005
87	7569	658503	9·3273791	4·431047
88	7744	681472	9·3808315	4·447960
89	7921	704969	9·4339811	4·464745
90	8100	729000	9·4868330	4·481405

Number.	Square.	Cube.	Square Root.	Cube Root.
91	8281	753571	9·5393920	4·497942
92	8464	778688	9·5916630	4·514357
93	8649	804357	9·6436508	4·530655
94	8836	830584	9·6953597	4·546836
95	9025	857375	9·7467943	4·562903
96	9216	884736	9·7979590	4·578857
97	9409	912673	9·8488578	4·594701
98	9604	941192	9·8994949	4·610436
99	9801	970299	9·9498744	4·626065
100	10000	1000000	10·0000000	4·641589
101	10201	1030301	10·0498756	4·657010
102	10404	1061208	10·0995049	4·672330
103	10609	1092727	10·1488916	4·687548
104	10816	1124864	10·1980390	4·702669
105	11025	1157625	10·2469508	4·717694
106	11236	1191016	10·2956301	4·732624
107	11449	1225043	10·3440804	4·747459
108	11664	1259712	10·3923048	4·762203
109	11881	1295029	10·4403065	4·776856
110	12100	1331000	10·4880885	4·791420
111	12321	1367631	10·5356538	4·805896
112	12544	1404928	10·5830052	4·820284
113	12769	1442897	10·6301458	4·834588
114	12996	1481544	10·6770783	4·848808
115	13225	1520875	10·7238053	4·862944
116	13456	1560896	10·7703296	4·876999
117	13689	1601613	10·8166538	4·890973
118	13924	1643032	10·8627805	4·904868
119	14161	1685159	10·9087121	4·918685
120	14400	1728000	10·9544512	4·932424
121	14641	1771561	11·0000000	4.946088
122	14884	1815848	11·0453610	4·959675
123	15129	1860867	11·0905365	4·973190
124	15376	1906624	11·1355287	4·986631
125	15625	1953125	11·1803399	5·000000
126	15876	2000376	11·2249722	5·013298
127	16129	2048383	11·2694277	5·026526
128	16384	2097152	11·3137085	5·039684
129	16641	2146689	11·3578167	5·052774
130	16900	2197000	11·4017543	5·065797
131	17161	2248091	11·4455231	5·078753
132	17424	2299968	11·4891253	5·091643
133	17689	2352637	11·5325626	5·104469
134	17956	2406104	11·5758369	5·117230
135	18225	2460375	11·6189500	5·129928

Number.	Square.	Cube.	Square Root.	Cube Root.
136	18496	2515456	11·6619038	5·142563
137	18769	2571353	11·7046999	5·155137
138	19044	2628072	11·7473444	5·167649
139	19321	2685619	11·7898261	5·180101
140	19600	2744000	11·8321596	5·192494
141	19881	2803221	11·8743421	5·204828
142	20164	2863288	11·9163753	5·217103
143	20449	2924207	11·9582607	5·229321
144	20736	2985984	12·0000000	5·241482
145	21025	3048625	12·0415946	5·253588
146	21316	3112136	12·0830460	5·265637
147	21609	3176523	12·1243557	5·277632
148	21904	3241792	12·1655251	5·289572
149	22201	3307949	12·2065556	5·301459
150	22500	3375000	12·2474487	5·313293
151	22801	3442951	12·2882057	5·325074
152	23104	3511808	12·3288280	5·336803
153	23409	3581577	12·3693169	5·348481
154	23716	3652264	12·4096736	5·360108
155	24025	3723875	12·4498996	5·371685
156	24336	3796416	12·4899960	5·383213
157	24649	3869893	12·5299641	5·394690
158	24964	3944312	12·5698051	5·406120
159	25281	4019679	12·6095202	5·417501
160	25600	4096000	12·6491106	5·428835
161	25921	4173281	12·6885775	5·440122
162	26244	4251528	12·7279221	5·451362
163	26569	4330747	12·7671453	5·462556
164	26896	4410944	12·8062485	5·473703
165	27225	4492125	12·8452326	5·484806
166	27556	4574296	12·8840987	5·495865
167	27889	4657463	12·9228480	5·506879
168	28224	4741632	12·9614814	5·517848
169	28561	4826809	13·0000000	5·528775
170	28900	4913000	13·0384048	5·539658
171	29241	5000211	13·0766968	5·550499
172	29584	5088448	13·1148770	5·561298
173	29929	5177717	13·1529464	5·572054
174	30276	5268024	13·1909060	5·582770
175	30625	5359375	13·2287566	5·593445
176	30976	5451776	13·2664992	5·604079
177	31329	5545233	13·3041347	5·614673
178	31684	5639752	13·3416641	5·625226
179	32041	5735339	13·3790882	5·635741
180	32400	5832000	13·4164079	5·646216

Number.	Square.	Cube.	Square Root.	Cube Root.
181	32761	5929741	13·4536240	5·656652
182	33124	6028568	13·4907376	5·667051
183	33489	6128487	13·5277493	5·677411
184	33856	6229504	13·5646600	5·687734
185	34225	6331625	13·6014705	5·698019
186	34596	6434856	13·6381817	5·708267
187	34969	6539203	13·6747943	5·718479
188	35344	6644672	13·7113092	5·728654
189	35721	6751269	13·7477271	5·738794
190	36100	6859000	13·7840488	5·748897
191	36481	6967871	13·8202750	5·758965
192	36864	7077888	13·8564065	5·768998
193	37249	7189057	13·8924440	5·778996
194	37636	7301384	13·9283883	5·788960
195	38025	7414875	13·9642400	5·798890
196	38416	7529536	14·0000000	5·808786
197	38809	7645373	14·0356688	5·818648
198	39204	7762392	14·0712473	5·828476
199	39601	7880599	14·1067360	5·838272
200	40000	8000000	14·1421356	5·848035
201	40401	8120601	14·1774469	5·857766
202	40804	8242408	14·2126704	5·867464
203	41209	8365427	14·2478068	5·877130
204	41616	8489664	14·2828569	5·886765
205	42025	8615125	14·3178211	5·896368
206	42436	8741816	14·3527001	5·905941
207	42849	8869743	14·3874946	5·915481
208	43264	8998912	14·4222051	5·924992
209	43681	9129329	14·4568323	5·934473
210	44100	9261000	14·4913767	5·943922
211	44521	9393931	14·5258390	5·953341
212	44944	9528128	14·5602198	5·962731
213	45369	9663597	14.5945195	5·972092
214	45796	9800344	14·6287388	5·981426
215	46225	9938375	14·6628783	5·990727
216	46656	10077696	14·6969385	6·000000
217	47089	10218313	14.7309199	6·009244
218	47524	10360232	14·7648231	6·018463
219	47961	10503459	14·7986486	6·027650
220	48400	10648000	14·8323970	6·036811
221	48841	10793861	14·8660687	6·045943
222	49284	10941048	14·8996644	6·055048
223	49729	11089567	14·9331845	6 064126
224	50176	11239424	14·9666295	6·073177
225	50625	11390625	15·0000000	6·082201

Number.	Square.	Cube.	Square Root.	Cube Root.
226	51076	11543176	15·0332964	6·091199
227	51529	11697083	15·0665192	6·100170
228	51984	11852352	15·0996689	6·109115
229	52441	12008989	15·1327460	6·118032
230	52900	12167000	15·1657509	6·126925
231	53361	12326391	15·1986842	6·135792
232	53824	12487168	15·2315462	6·144634
233	54289	12649337	15·2643375	6·153449
234	54756	12812904	15·2970585	6·162239
235	55225	12977875	15·3297097	6·171005
236	55696	13144256	15·3622915	6·179747
237	56169	13312053	15·3948043	6·188463
238	56644	13481272	15·4272486	6·197154
239	57121	13651919	15·4596248	6·205821
240	57600	13824000	15·4919334	6·214464
241	58081	13997521	15·5241747	6·223084
242	58564	14172488	15·5563492	6·231678
243	59049	14348907	15·5884573	6·240251
244	59536	14526784	15·6204994	6·248800
245	60025	14706125	15·6524758	6·257324
246	60516	14886936	15·6843871	6·265826
247	61009	15069223	15·7162336	6·274304
248	61504	15252992	15·7480157	6·282760
249	62001	15438249	15·7797338	6·291194
250	62500	15625000	15·8113883	6·299604
251	63001	15813251	15·8429795	6·307992
252	63504	16003008	15·8745079	6·316359
253	64009	16194277	15·9059737	6·324704
254	64516	16387064	15·9373775	6·333025
255	65025	16581375	15·9687194	6·341325
256	65536	16777216	16·0000000	6·349602
257	66049	16974593	16·0312195	6·357859
258	66564	17173512	16·0623784	6·366096
259	67081	17373979	16·0934769	6·374310
260	67600	17576000	16·1245155	6·382504
261	68121	17779581	16·1554944	6·390676
262	68644	17984728	16·1864141	6·398827
263	69169	18191447	16·2172747	6·406958
264	69696	18399744	16·2480768	6·415068
265	70225	18609625	16·2788206	6·423157
266	70756	18821096	16·3095064	6·431226
267	71289	19034163	16·3401346	6·439276
268	71824	19248832	16·3707055	6·447305
269	72361	19465109	16·4012195	6·455314
270	72900	19683000	16·4316767	6·463304

Number.	Square.	Cube.	Square Root.	Cube Root.
271	73441	19902511	16·4620776	6·471274
272	73984	20123648	16·4924225	6·479224
273	74529	20346417	16·5227116	6·487153
274	75076	20570824	16·5529454	6·495064
275	75625	20796875	16·5831240	6·502956
276	76176	21024576	16·6132477	6·510829
277	76729	21253933	16·6433170	6·518684
278	77284	21484952	16·6733320	6·526519
279	77841	21717639	16·7032931	6·534335
280	78400	21952000	16·7332005	6·542132
281	78961	22188041	16·7630546	6·549911
282	79524	22425768	16·7928556	6·557672
283	80089	22665187	16·8226038	6·565415
284	80656	22906304	16·8522995	6·573139
285	81225	23149125	16·8819430	6·580844
286	81796	23393656	16·9115345	6·588531
287	82369	23639903	16·9410743	6·596202
288	82944	23887872	16·9705627	6·603854
289	83521	24137569	17·0000000	6·611488
290	84100	24389000	17·0293864	6·619106
291	84681	24642171	17·0587221	6·626705
292	85264	24897088	17·0880075	6·634287
293	85849	25153757	17·1172428	6·641851
294	86436	25412184	17·1464282	6·649399
295	87025	25672375	17·1755640	6·656930
296	87616	25934336	17·2046505	6·664443
297	88209	26198073	17·2336879	6·671940
298	88804	26463592	17·2626765	6·679419
299	89401	26730899	17·2916165	6·686882
300	90000	27000000	17·3205081	6·694328
301	90601	27270901	17·3493516	6·701759
302	91204	27543608	17·3781472	6·709172
303	91809	27818127	17·4068952	6·716569
304	92416	28094464	17·4355958	6·723950
305	93025	28372625	17·4642492	6·731316
306	93636	28652616	17·4928557	6·738665
307	94249	28934443	17·5214155	6·745997
308	94864	29218112	17·5499288	6·753313
309	95481	29503629	17·5783958	6·760614
310	96100	29791000	17·6068169	6·767899
311	96721	30080231	17·6351921	6·775168
312	97344	30371328	17·6635217	6·782422
313	97969	30664297	17·6918060	6·789661
314	98596	30959144	17·7200451	6·796884
315	99225	31255875	17·7482393	6·804091

Number.	Square.	Cube.	Square Root.	Cube Root.
316	99856	31554496	17·7763888	6·811284
317	100489	31855013	17·8044938	6·818461
318	101124	32157432	17·8325545	6·825624
319	101761	32461759	17·8605711	6·832771
320	102400	32768000	17·8885438	6·839903
321	103041	33076161	17·9164729	6·847021
322	103684	33386248	17·9443584	6·854124
323	104329	33698267	17·9722008	6·861211
324	104976	34012224	18·0000000	6·868285
325	105625	34328125	18·0277564	6·875343
326	106276	34645976	18·0554701	6·882388
327	106929	34965783	18·0831413	6·889419
328	107584	35287552	18·1107703	6·896435
329	108241	35611289	18·1383571	6·903436
330	108900	35937000	18·1659021	6·910423
331	109561	36264691	18·1934054	6·917396
332	110224	36594368	18·2208672	6·924355
333	110889	36926037	18·2482876	6·931300
334	111556	37259704	18·2756669	6·938232
335	112225	37595375	18·3030052	6·945149
336	112896	37933056	18·3303028	6·952053
337	113569	38272753	18·3575598	6·958943
338	114244	38614472	18·3847763	6·965819
339	114921	38958219	18·4119526	6·972682
340	115600	39304000	18·4390889	6·979532
341	116281	39651821	18·4661853	6·986369
342	116964	40001688	18·4932420	6·993191
343	117649	40353607	18·5202592	7·000000
344	118336	40707584	18·5472370	7·006796
345	119025	41063625	18·5741756	7·013579
346	119716	41421736	18·6010752	7·020349
347	120409	41781923	18·6279360	7·027106
348	121104	42144192	18·6547581	7·033850
349	121801	42508549	18·6815417	7·040581
350	122500	42875000	18·7082869	7·047298
351	123201	43243551	18·7349940	7·054003
352	123904	43614208	18·7616630	7·060696
353	124609	43986977	18·7882942	7·067376
354	125316	44361864	18·8148877	7·074043
355	126025	44738875	18·8414437	7·080698
356	126736	45118016	18·8679623	7·087341
357	127449	45499293	18·8944436	7·093970
358	128164	45882712	18·9208879	7·100588
359	128881	46268279	18·9472953	7·107193
360	129600	46656000	18·9736660	7·113786

Number.	Square.	Cube.	Square Root.	Cube Root.
361	130321	47045881	19·0000000	7·120367
362	131044	47437928	19·0262976	7·126935
363	131769	47832147	19·0525589	7·133492
364	132496	48228544	19·0787840	7·140037
365	133225	48627125	19·1049732	7·146569
366	133956	49027896	19·1311265	7·153090
367	134689	49430863	19·1572441	7·159599
368	135424	49836032	19·1833261	7·166095
369	136161	50243409	19·2093727	7·172580
370	136900	50653000	19·2353841	7·179054
371	137641	51064811	19·2613603	7·185516
372	138384	51478848	19·2873015	7·191966
373	139129	51895117	19·3132079	7·198405
374	139876	52313624	19·3390796	7·204832
375	140625	52734375	19·3649167	7·211247
376	141376	53157376	19·3907194	7·217652
377	142129	53582633	19·4164878	7·224045
378	142884	54010152	19·4422221	7·230427
379	143641	54439939	19·4679223	7·236797
380	144400	54872000	19·4935887	7·243156
381	145161	55306341	19·5192213	7·249504
382	145924	55742968	19·5448203	7·255841
383	146689	56181887	19·5703858	7·262167
384	147456	56623104	19·5959179	7·268482
385	148225	57066625	19·6214169	7·274786
386	148996	57512456	19·6468827	7·281079
387	149769	57960603	19·6723156	7·287362
388	150544	58411072	19·6977156	7·293633
389	151321	58863869	19·7230829	7·299893
390	152100	59319000	19·7484177	7·306143
391	152881	59776471	19·7737199	7·312383
392	153664	60236288	19·7989899	7·318611
393	154449	60698457	19·8242276	7·324829
394	155236	61162984	19·8494332	7·331037
395	156025	61629875	19·8746069	7·337234
396	156816	62099136	19·8997487	7·343420
397	157609	62570773	19·9248588	7·349596
398	158404	63044792	19·9499373	7·355762
399	159201	63521199	19·9749844	7·361917
400	160000	64000000	20·0000000	7·368063
401	160801	64481201	20·0249844	7·374198
402	161604	64964808	20·0499377	7·380322
403	162409	65450827	20·0748599	7·386437
404	163216	65939264	20·0997512	7·392542
405	164025	66430125	20·1246118	7·398636

Number.	Square.	Cube.	Square Root.	Cube Root.
406	164836	66923416	20·1494417	7·404720
407	165649	67419143	20·1742410	7·410794
408	166464	67917312	20·1990099	7·416859
409	167281	68417929	20·2237484	7·422914
410	168100	68921000	20·2484567	7·428958
411	168921	69426531	20·2731349	7·434993
412	169744	69934528	20·2977831	7·441018
413	170569	70444997	20·3224014	7·447034
414	171396	70957944	20·3469899	7·453039
415	172225	71473375	20·3715488	7·459036
416	173056	71991296	20·3960781	7·465022
417	173889	72511713	20·4205779	7·470999
418	174724	73034632	20·4450483	7·476966
419	175561	73560059	20·4694895	7·482924
420	176400	74088000	20·4939015	7·488872
421	177241	74618461	20·5182845	7·494810
422	178084	75151448	20·5426386	7·500740
423	178929	75686967	20·5669638	7·506660
424	179776	76225024	20·5912603	7·512571
425	180625	76765625	20·6155281	7·518473
426	181476	77308776	20·6397674	7·524365
427	182329	77854483	20·6639783	7·530248
428	183184	78402752	20·6881609	7·536122
429	184041	78953589	20·7123152	7·541986
430	184900	79507000	20·7364414	7·547842
431	185761	80062991	20·7605395	7·553688
432	186624	80621568	20·7846097	7·559525
433	187489	81182737	20·8086520	7·565355
434	188356	81746504	20·8326667	7·571173
435	189225	82312875	20·8566536	7·576984
436	190096	82881856	20.8806130	7·582786
437	190969	83453453	20·9045450	7·588579
438	191844	84027672	20·9284495	7·594363
439	192721	84604519	20·9523268	7·600138
440	193600	85184000	20·9761770	7·605905
441	194481	85766121	21·0000000	7·611662
442	195364	86350888	21·0237960	7·617411
443	196249	86938307	21·0475652	7·623151
444	197136	87528384	21·0713075	7·628883
445	198025	88121125	21.0950231	7·634606
446	198916	88716536	21·1187121	7·640321
447	199809	89314623	21·1423745	7·646027
448	200704	89915392	21·1660105	7·651725
449	201601	90518849	21·1896201	7·657414
450	202500	91125000	21·2132034	7·663094

Number.	Square.	Cube.	Square Root.	Cube Root.
451	203401	91733851	21·2367606	7·668766
452	204304	92345408	21·2602916	7·674430
453	205209	92959677	21·2837967	7·680085
454	206116	93576664	21·3072758	7·685732
455	207025	94196375	21·3307290	7·691371
456	207936	94818816	21·3541565	7·697002
457	208849	95443993	21·3775583	7·702624
458	209764	96071912	21·4009346	7·708238
459	210681	96702579	21·4242853	7·713844
460	211600	97336000	21·4476106	7·719442
461	212521	97972181	21·4709106	7·725032
462	213444	98611128	21·4941853	7·730614
463	214369	99252847	21·5174348	7·736187
464	215296	99897344	21·5406592	7·741753
465	216225	100544625	21·5638587	7·747310
466	217156	101194696	21·5870331	7·752860
467	218089	101847563	21·6101828	7·758402
468	219024	102503232	21·6333077	7·763936
469	219961	103161709	21·6564078	7·769462
470	220900	103823000	21·6794834	7·774980
471	221841	104487111	21·7025344	7·780490
472	222784	105154048	21·7255610	7·785992
473	223729	105823817	21·7485632	7·791487
474	224676	106496424	21·7715411	7·796974
475	225625	107171875	21·7944947	7·802453
476	226576	107850176	21·8174242	7·807925
477	227529	108531333	21·8403297	7·813389
478	228484	109215352	21·8632111	7·818845
479	229441	109902239	21·8860686	7·824294
480	230400	110592000	21·9089023	7·829735
481	231361	111284641	21·9317122	7·835168
482	232324	111980168	21·9544984	7·840594
483	233289	112678587	21·9772610	7·846013
484	234256	113379904	22·0000000	7·851424
485	235225	114084125	22·0227155	7·856828
486	236196	114791256	22·0454077	7·862224
487	237169	115501303	22·0680765	7·867613
488	238144	116214272	22·0907220	7·872994
489	239121	116930169	22·1133444	7·878368
490	240100	117649000	22·1359436	7·883735
491	241081	118370771	22·1585198	7·889095
492	242064	119095488	22·1810730	7·894446
493	243049	119823157	22·2036033	7·899791
494	244036	120553784	22·2261108	7·905129
495	245025	121287375	22·2485955	7·910460

Number.	Square.	Cube.	Square Root.	Cube Root.
496	246016	122023936	22·2710575	7·915784
497	247009	122763473	22·2934968	7·921100
498	248004	123505992	22·3159136	7·926408
499	249001	124251499	22·3383079	7·931710
500	250000	125000000	22·3606798	7·937005
501	251001	125751501	22·3830293	7·942293
502	252004	126506008	22·4053565	7·947573
503	253009	127263527	22·4276615	7·952847
504	254016	128024064	22·4499443	7·958114
505	255025	128787625	22·4722051	7·963374
506	256036	129554216	22·4944438	7·968627
507	257049	130323843	22·5166605	7·973873
508	258064	131096512	22·5388553	7·979112
509	259081	131872229	22·5610283	7·984344
510	260100	132651000	22·5831796	7·989569
511	261121	133432831	22·6053091	7·994788
512	262144	134217728	22·6274170	8·000000
513	263169	135005697	22·6495033	8·005205
514	264196	135796744	22·6715681	8·010403
515	265225	136590875	22·6936114	8·015595
516	266256	137388096	22·7156334	8·020779
517	267289	138188413	22·7376340	8·025957
518	268324	138991832	22·7596134	8·031129
519	269361	139798359	22·7815715	8·036293
520	270400	140608000	22·8035085	8·041451
521	271441	141420761	22·8254244	8·046603
522	272484	142236648	22·8473193	8·051748
523	273529	143055667	22·8691933	8·056886
524	274576	143877824	22·8910463	8·062018
525	275625	144703125	22·9128785	8·067143
526	276676	145531576	22·9346899	8·072262
527	277729	146363183	22·9564806	8·077374
528	278784	147197952	22·9782506	8·082480
529	279841	148035889	23·0000000	8·087579
530	280900	148877000	23·0217289	8·092672
531	281961	149721291	23·0434372	8·097758
532	283024	150568768	23·0651252	8·102839
533	284089	151419437	23·0867928	8·107912
534	285156	152273304	23.1084400	8·112980
535	286225	153130375	23·1300670	8·118041
536	287296	153990656	23·1516738	8·123096
537	288369	154854153	23·1732605	8·128144
538	289444	155720872	23·1948270	8·133186
539	290521	156590819	23·2163735	8·138223
540	291600	157464000	23·2379001	8·143253

Number.	Square.	Cube.	Square Root.	Cube Root.
541	292681	158340421	23·2594067	8·148276
542	293764	159220088	23·2808935	8·153293
543	294849	160103007	23·3023604	8·158305
544	295936	160989184	23·3238076	8·163309
545	297025	161878625	23·3452351	8·168309
546	298116	162771336	23·3666429	8·173302
547	299209	163667323	23·3880311	8·178289
548	300304	164566592	23·4093998	8·183269
549	301401	165469149	23·4307490	8·188244
550	302500	166375000	23·4520788	8·193212
551	303601	167284151	23·4733892	8·198175
552	304704	168196608	23·4946802	8·203131
553	305809	169112377	23·5159520	8·208082
554	306916	170031464	23·5372046	8·213027
555	308025	170953875	23·5584380	8·217965
556	309136	171879616	23·5796522	8·222898
557	310249	172808693	23·6008474	8·227825
558	311364	173741112	23·6220236	8·232746
559	312481	174676879	23·6431808	8·237661
560	313600	175616000	23·6643191	8·242570
561	314721	176558481	23·6854386	8·247474
562	315844	177504328	23·7065392	8·252371
563	316969	178453547	23·7276210	8·257263
564	318096	179406144	23·7486842	8·262149
565	319225	180362125	23·7697286	8·267029
566	320356	181321496	23·7907545	8·271903
567	321489	182284263	23·8117618	8·276772
568	322624	183250432	23·8327506	8·281635
569	323761	184220009	23·8537209	8·286493
570	324900	185193000	23·8746728	8·291344
571	326041	186169411	23·8956063	8·296190
572	327184	187149248	23·9165215	8·301030
573	328329	188132517	23·9374184	8·305865
574	329476	189119224	23·9582971	8·310694
575	330625	190109375	23·9791576	8·315517
576	331776	191102976	24·0000000	8·320335
577	332929	192100033	24·0208243	8·325147
578	334084	193100552	24·0416306	8·329954
579	335241	194104539	24·0624188	8·334755
580	336400	195112000	24·0831892	8·339551
581	337561	196122941	24·1039416	8·344341
582	338724	197137368	24·1246762	8·349125
583	339889	198155287	24·1453929	8·353904
584	341056	199176704	24·1660919	8·358678
585	342225	200201625	24·1867732	8·363446

Number.	Square.	Cube.	Square Root.	Cube Root.
586	343396	201230056	24·2074369	8·368209
587	344569	202262003	24·2280929	8·372966
588	345744	203297472	24·2487113	8·377718
589	346921	204336469	24·2693222	8·382465
590	348100	205379000	24·2899156	8·387206
591	349281	206425071	24·3104916	8·391942
592	350464	207474688	24·3310501	8·396673
593	351649	208527857	24·3515913	8·401398
594	352836	209584584	24·3721152	8·406118
595	354025	210644875	24·3926218	8·410832
596	355216	211708736	24·4131112	8·415542
597	356409	212776173	24·4335834	8·420246
598	357604	213847192	24·4540385	8·424944
599	358801	214921799	24·4744765	8·429638
600	360000	216000000	24·4948974	8·434327
601	361201	217081801	24·5153013	8·439009
602	362404	218167208	24·5356883	8·443687
603	363609	219256227	24·5560583	8·448360
604	364816	220348864	24·5764115	8·453028
605	366025	221445125	24·5967478	8·457690
606	367236	222545016	24·6170673	8·462347
607	368449	223648543	24·6373700	8·466999
608	369664	224755712	24·6576560	8·471647
609	370881	225866529	24·6779254	8·476289
610	372100	226981000	24·6981781	8·480926
611	373321	228099131	24·7184142	8·485557
612	374544	229220928	24·7386338	8·490184
613	375769	230346397	24·7588368	8·494806
614	376996	231475544	24·7790234	8·499423
615	378225	232608375	24·7991935	8·504035
616	379456	233744896	24·8193473	8·508641
617	380689	234885113	24·8394847	8·513243
618	381924	236029032	24·8596058	8·517840
619	383161	237176659	24·8797106	8·522432
620	384400	238328000	24·8997992	8·527018
621	385641	239483061	24·9198716	8·531600
622	386884	240641848	24·9399278	8·536178
623	388129	241804367	24·9599679	8·540750
624	389376	242970624	24·9799920	8·545317
625	390625	244140625	25·0000000	8·549879
626	391876	245314376	25·0199920	8·554437
627	393129	246491883	25·0399681	8·558990
628	394384	247673152	25·0599282	8·563537
629	395641	248858189	25·0798724	8·568080
630	396900	250047000	25·0998008	8·572618

Number.	Square.	Cube.	Square Root.	Cube Root.
631	398161	251239591	25·1197134	8·577152
632	399424	252435968	25·1396102	8·581680
633	400689	253636137	25·1594913	8·586204
634	401956	254840104	25·1793566	8·590723
635	403225	256047875	25·1992063	8·595238
636	404496	257259456	25·2190404	8·599747
637	405769	258474853	25·2388589	8·604252
638	407044	259694072	25·2586619	8·608752
639	408321	260917119	25·2784493	8·613248
640	409600	262144000	25·2982213	8·617738
641	410881	263374721	25·3179778	8·622224
642	412164	264609288	25·3377189	8·626706
643	413449	265847707	25·3574447	8·631183
644	414736	267089984	25·3771551	8·635655
645	416025	268336125	25·3968502	8·640122
646	417316	269586136	25·4165301	8·644585
647	418609	270840023	25·4361947	8·649043
648	419904	272097792	25·4558441	8·653497
649	421201	273359449	25·4754784	8·657946
650	422500	274625000	25·4950976	8·662391
651	423801	275894451	25·5147016	8·666831
652	425104	277167808	25·5342907	8·671266
653	426409	278445077	25·5538647	8·675697
654	427716	279726264	25·5734237	8·680123
655	429025	281011375	25·5929678	8·684545
656	430336	282300416	25·6124969	8·688963
657	431649	283593393	25·6320112	8·693376
658	432964	284890312	25·6515107	8·697784
659	434281	286191179	25·6709953	8·702188
660	435600	287496000	25·6904652	8·706587
661	436921	288804781	25·7099208	8·710982
662	438244	290117528	25·7293607	8·715373
663	439569	291434247	25·7487864	8·719759
664	440896	292754944	25·7681975	8·724141
665	442225	294079625	25·7875939	8·728518
666	443556	295408296	25·8069758	8·732891
667	444889	296740963	25·8263431	8·737260
668	446224	298077632	25·8456960	8·741624
669	447561	299418309	25·8650343	8·745984
670	448900	300763000	25·8843582	8·750340
671	450241	302111711	25·9036677	8·754691
672	451584	303464448	25·9229628	8·759038
673	452929	304821217	25·9422435	8·763380
674	454276	306182024	25·9615100	8·767719
675	455625	307546875	25·9807621	8·772053

Number.	Square.	Cube.	Square Root.	Cube Root.
676	456976	308915776	26·0000000	8·776382
677	458329	310288733	26·0192237	8·780708
678	459684	311665752	26·0384331	8·785029
679	461041	313046839	26·0576284	8·789346
680	462400	314432000	26·0768096	8·793659
681	463761	315821241	26·0959767	8·797967
682	465124	317214568	26·1151297	8·802272
683	466489	318611987	26·1342687	8·806572
684	467856	320013504	26·1533937	8·810868
685	469225	321419125	26·1725047	8·815159
686	470596	322828856	26·1916017	8·819447
687	471969	324242703	26·2106848	8·823730
688	473344	325660672	26·2297541	8·828009
689	474721	327082769	26·2488095	8·832285
690	476100	328509000	26·2678511	8·836556
691	477481	329939371	26·2868789	8·840822
692	478864	331373888	26·3058929	8·845085
693	480249	332812557	26·3248932	8·849344
694	481636	334255384	26·3438797	8·853598
695	483025	335702375	26·3628527	8·857849
696	484416	337153536	26·3818119	8·862095
697	485809	338608873	26·4007576	8·866337
698	487204	340068392	26·4196896	8·870575
699	488601	341532099	26·4386081	8·874809
700	490000	343000000	26·4575131	8·879040
701	491401	344472101	26·4764046	8·883266
702	492804	345948408	26·4952826	8·887488
703	494209	347428927	26·5141472	8·891706
704	495616	348913664	26·5329983	8·895920
705	497025	350402625	26·5518361	8·900130
706	498436	351895816	26·5706605	8·904336
707	499849	353393243	26·5894716	8·908538
708	501264	354894912	26·6082694	8·912736
709	502681	356400829	26·6270539	8·916931
710	504100	357911000	26·6458252	8·921121
711	505521	359425431	26·6645833	8·925307
712	506944	360944128	26·6833281	8·929490
713	508369	362467097	26·7020598	8·933668
714	509796	363994344	26·7207784	8·937843
715	511225	365525875	26·7394839	8·942014
716	512656	367061696	26·7581763	8·946180
717	514089	368601813	26·7768557	8·950343
718	515524	370146232	26·7955220	8·954502
719	516961	371694959	26·8141754	8·958658
720	518400	373248000	26·8328157	8·962809

Number.	Square.	Cube.	Square Root.	Cube Root.
721	519841	374805361	26·8514432	8·966957
722	521284	376367048	26·8700577	8·971100
723	522729	377933067	26·8886593	8·975240
724	524176	379503424	26·9072481	8·979376
725	525625	381078125	26·9258240	8·983508
726	527076	382657176	26·9443872	8·987637
727	528529	384240583	26·9629375	8·991762
728	529984	385828352	26·9814751	8·995883
729	531441	387420489	27·0000000	9·000000
730	532900	389017000	27·0185122	9·004113
731	534361	390617891	27·0370117	9·008222
732	535824	392223168	27·0554985	9.012328
733	537289	393832837	27·0739727	9·016430
734	538756	395446904	27·0924344	9·020529
735	540225	397065375	27·1108834	9·024623
736	541696	398688256	27·1293199	9·028714
737	543169	400315553	27·1477439	9·032802
738	544644	401947272	27·1661554	9·036885
739	546121	403583419	27·1845544	9·040965
740	547600	405224000	27·2029410	9·045041
741	549081	406869021	27·2213152	9·049114
742	550564	408518488	27·2396769	9·053183
743	552049	410172407	27·2580263	9·057248
744	553536	411830784	27·2763634	9·061309
745	555025	413493625	27·2946881	9·065367
746	556516	415160936	27·3130006	9·069422
747	558009	416832723	27·3313007	9·073472
748	559504	418508992	27·3495887	9·077519
749	561001	420189749	27·3678644	9·081563
750	562500	421875000	27·3861279	9·085603
751	564001	423564751	27·4043792	9·089639
752	565504	425259008	27·4226184	9·093672
753	567009	426957777	27·4408455	9·097701
754	568516	428661064	27·4590604	9·101726
755	570025	430368875	27·4772633	9·105748
756	571536	432081216	27·4954542	9·109766
757	573049	433798093	27·5136330	9·113781
758	574564	435519512	27·5317998	9·117793
759	576081	437245479	27·5499546	9·121801
760	577600	438976000	27·5680975	9·125805
761	579121	440711081	27·5862284	9·129806
762	580644	442450728	27·6043475	9·133803
763	582169	444194947	27·6224546	9·137797
764	583696	445943744	27·6405499	9·141788
765	585225	447697125	27·6586334	9·145774

Number.	Square.	Cube.	Square Root.	Cube Root.
766	586756	449455096	27·6767050	9·149757
767	588289	451217663	27·6947648	9·153737
768	589824	452984832	27·7128129	9·157713
769	591361	454756609	27·7308492	9·161686
770	592900	456533000	27·7488739	9·165656
771	594441	458314011	27·7668868	9·169622
772	595984	460099648	27·7848880	9·173585
773	597529	461889917	27·8028775	9·177544
774	599076	463684824	27·8208555	9·181500
775	600625	465484375	27·8388218	9·185452
776	602176	467288576	27·8567766	9·189401
777	603729	469097433	27·8747197	9·193347
778	605284	470910952	27·8926514	9·197289
779	606841	472729139	27·9105715	9·201228
780	608400	474552000	27·9284801	9·205164
781	609961	476379541	27·9463772	9·209096
782	611524	478211768	27·9642629	9·213025
783	613089	480048687	27·9821372	9·216950
784	614656	481890304	28·0000000	9·220872
785	616225	483736625	28·0178515	9·224791
786	617796	485587656	28·0356915	9·228706
787	619369	487443403	28·0535203	9·232618
788	620944	489303872	28·0713377	9·236527
789	622521	491169069	28·0891438	9·240433
790	624100	493039000	28·1069386	9·244335
791	625681	494913671	28·1247222	9·248234
792	627264	496793088	28·1424946	9·252130
793	628849	498677257	28·1602557	9·256022
794	630436	500566184	28·1780056	9·259911
795	632025	502459875	28·1957444	9·263797
796	633616	504358336	28·2134720	9·267679
797	635209	506261573	28·2311884	9·271559
798	636804	508169592	28·2488938	9·275435
799	638401	510082399	28·2665881	9·279308
800	640000	512000000	28·2842712	9·283177
801	641601	513922401	28·3019434	9·287044
802	643204	515849608	28·3196045	9·290907
803	644809	517781627	28·3372546	9·294767
804	646416	519718464	28·3548938	9·298623
805	648025	521660125	28·3725219	9·302477
806	649636	523606616	28·3901391	9·306327
807	651249	525557943	28·4077454	9·310175
808	652864	527514112	28·4253408	9·314019
809	654481	529475129	28·4429253	9·317859
810	656100	531441000	28·4604989	9·321697

Number.	Square.	Cube.	Square Root.	Cube Root.
811	657721	533411731	28·4780617	9·325532
812	659344	535387328	28·4956137	9·329363
813	660969	537366797	28·5131549	9·333191
814	662596	539353144	28·5306852	9·337016
815	664225	541343375	28·5482048	9·340838
816	665856	543338496	28·5653137	9·344657
817	667489	545338513	28·5832119	9·348473
818	669124	547343432	28·6006993	9·352285
819	670761	549353259	28·6181760	9·356095
820	672400	551368000	28·6356421	9·359901
821	674041	553387661	28·6530976	9·363704
822	675684	555412248	28·6705424	9·367505
823	677329	557441767	28·6879766	9·371302
824	678976	559476224	28·7054002	9·375096
825	680625	561515625	28·7228132	9·378887
826	682276	563559976	28·7402157	9·382675
827	683929	565609283	28·7576077	9·386460
828	685584	567663552	28·7749891	9·390241
829	687241	569722789	28·7923601	9·394020
830	688900	571787000	28·8097206	9·397796
831	690561	573856191	28·8270706	9·401569
832	692224	575930368	28·8444102	9·405338
833	693889	578009537	28·8617394	9·409105
834	695556	580093704	28·8790582	9·412869
835	697225	582182875	28·8963666	9·416630
836	698896	584277056	28·9136646	9·420387
837	700569	586376253	28·9309523	9·424142
838	702244	588480472	28·9482297	9·427893
839	703921	590589719	28·9654967	9·431642
840	705600	592704000	28·9827535	9·435388
841	707281	594823321	29·0000000	9·439130
842	708964	596947688	29·0172363	9·442870
843	710649	599077107	29·0344623	9·446607
844	712336	601211584	29·0516781	9·450341
845	714025	603351125	29·0688837	9·454071
846	715716	605495736	29·0860791	9·457799
847	717409	607645423	29·1032644	9·461524
848	719104	609800192	29·1204396	9·465247
849	720801	611960049	29·1376046	9·468966
850	722500	614125000	29·1547595	9·472682
851	724201	616295051	29·1719043	9·476395
852	725904	618470208	29·1890390	9·480106
853	727609	620650477	29·2061637	9·483813
854	729316	622835864	29·2232784	9·487518
855	731025	625026375	29·2403830	9·491219

Number.	Square.	Cube.	Square Root.	Cube Root.
856	732736	627222016	29·2574777	9·494918
857	734449	629422793	29·2745623	9·498614
858	736164	631628712	29·2916370	9·502307
859	737881	633839779	29·3087018	9·505998
860	739600	636056000	29·3257566	9·509685
861	741321	638277381	29·3428015	9·513369
862	743044	640503928	29·3598365	9·517051
863	744769	642735647	29·3768616	9·520730
864	746496	644972544	29·3938769	9·524406
865	748225	647214625	29·4108823	9·528079
866	749956	649461896	29·4278779	9·531749
867	751689	651714363	29·4448637	9·535417
868	753424	653972032	29·4618397	9·539081
869	755161	656234909	29·4788059	9·542743
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872	760384	663054848	29·5296461	9·553712
873	762129	665338617	29·5465734	9·557363
874	763876	667627624	29·5634910	9·561010
875	765625	669921875	29·5803989	9·564655
876	767376	672221376	29·5972972	9·568298
877	769129	674526133	29·6141858	9·571937
878	770884	676836152	29·6310648	9·575574
879	772641	679151439	29·6479342	9·579208
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881	776161	683797841	29·6816442	9·586468
882	777924	686128968	29·6984848	9·590093
883	779689	688465387	29·7153159	9·593716
884	781456	690807104	29·7321375	9·597337
885	783225	693154125	29·7489496	9·600954
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891	793881	707347971	29·8496231	9·622603
892	795664	709732288	29·8663690	9·626201
893	797449	712121957	29·8831056	9·629797
894	799236	714516984	29·8998328	9·633390
895	801025	716917375	29·9165506	9·636981
896	802816	719323136	29·9332591	9·640569
897	804609	721734273	29·9499583	9·644154
898	806404	724150792	29·9666481	9·647736
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905	819025	741217625	30·0832179	9·672740
906	820836	743677416	30·0998339	9·676301
907	822649	746142643	30·1164407	9·679860
908	824464	748613312	30·1330383	9·683416
909	826281	751089429	30·1496269	9·686970
910	828100	753571000	30·1662063	9·690521
911	829921	756058031	30·1827765	9·694069
912	831744	758550528	30·1993377	9·697615
913	833569	761048497	30·2158899	9·701158
914	835396	763551944	30·2324329	9·704698
915	837225	766060875	30·2489669	9·708236
916	839056	768575296	30·2654919	9·711772
917	840889	771095213	30·2820079	9·715305
918	842724	773620632	30·2985148	9·718835
919	844561	776151559	30·3150128	9·722363
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925	855625	791453125	30·4138127	9·743475
926	857476	794022776	30·4302481	9·746985
927	859329	796597983	30·4466747	9·750493
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942	887364	835896888	30·6920185	9·802803
943	889249	838561807	30·7083051	9·806271
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948	898704	851971392	30·7896086	9·823572
949	900601	854670349	30·8058436	9·827025
950	902500	857375000	30·8220700	9·830475
951	904401	860085351	30·8382879	9·833923
952	906304	862801408	30·8544972	9·837369
953	908209	865523177	30·8706981	9·840812
954	910116	868250664	30·8868904	9·844253
955	912025	870983875	30·9030743	9·847692
956	913936	873722816	30·9192497	9·851128
957	915849	876467493	30·9354166	9·854561
958	917764	879217912	30·9515751	9·857992
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962	925444	890277128	31·0161248	9·871694
963	927369	893056347	31·0322413	9·875113
964	929296	895841344	31·0483494	9·878530
965	931225	898632125	31·0644491	9·881945
966	933156	901428696	31·0805405	9·885357
967	935089	904231063	31·0966236	9·888767
968	937024	907039232	31·1126984	9·892174
969	938961	909853209	31·1287648	9·895580
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971	942841	915498611	31·1608729	9·902383
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973	946729	921167317	31·1929479	9·909177
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981	962361	944076141	31·3209195	9·936261
982	964324	946966168	31·3368792	9·939636
983	966289	949862087	31·3528308	9·943009
984	968256	952763904	31·3687743	9·946379
985	970225	955671625	31·3847097	9·949747
986	972196	958585256	31·4006369	9·953113
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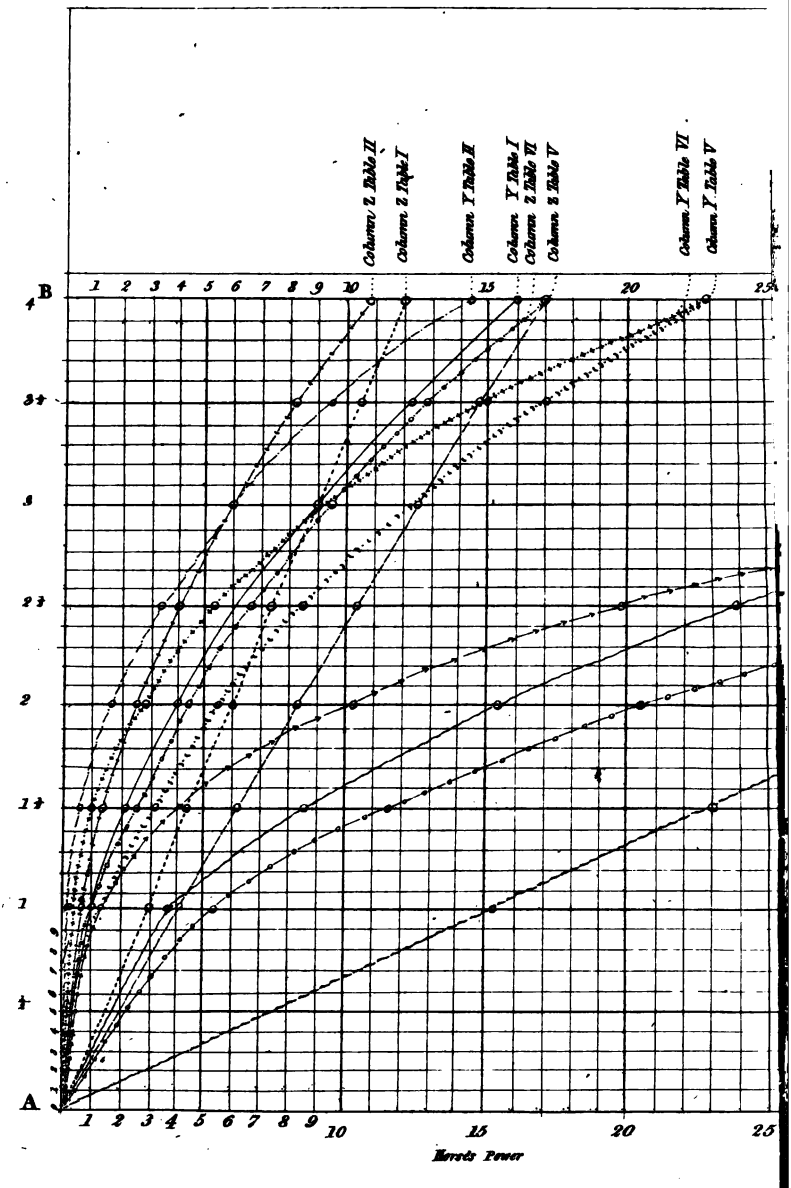
992	984064	976191488	31·4960315	9·973262
993	986049	979146657	31·5119025	9·976612
994	988036	982107784	31·5277655	9·979959
995	990025	985074875	31·5436206	9·983305
996	992016	988047936	31·5594677	9·986648
997	994009	991026973	31·5753068	9·989990
998	996004	994011992	31·5911380	9·993328
999	998001	997002999	31·6069613	9·996665

*** In this edition some errors in the table of Dr. Hutton have been corrected. The most extensive and accurate tables of the powers of numbers, are those published by Professor Barlow of the Royal Military Academy, entitled *New Mathematical Tables*, which also contain tables of prime numbers and factors, so useful in arranging the numbers of wheel work. (Ed.)


Column 2. Table II
Column 2. Table I
Column V. Table II
Column V. Table I
Column 2. Table VI
Column 2. Table V
Column V. Table VI
Column V. Table V
B
A
1 2 3 4 5 6 7 8 9 10 15 20 25
4
3½
3
2½
2
1½
1
½
Horse Power

CHART

PLATE II.

Fig. 1st

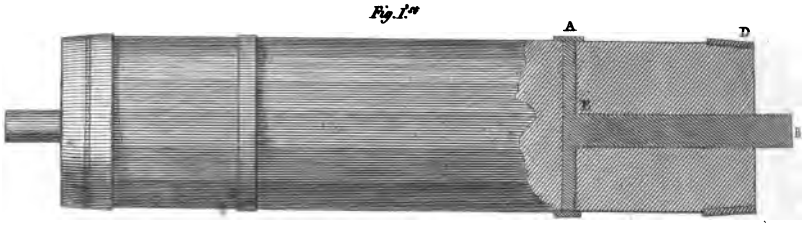


Fig. 1 N° 2.
End View

Fig. 1 N° 3.

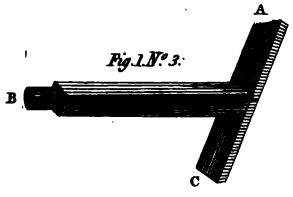


Fig. 2 N° 2.
End View.

Fig. 2d

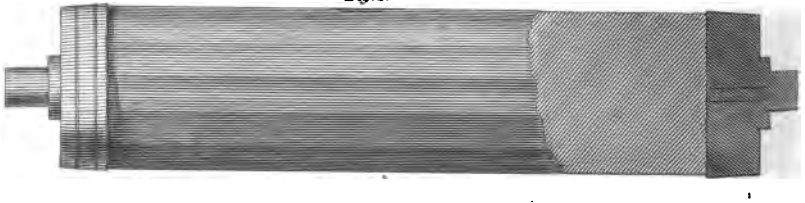


Fig. 6 N° 2.
End View.

Fig. 5th

Fig. 3d

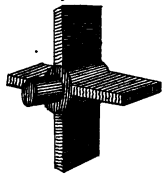


Fig. 4th

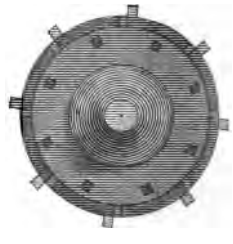
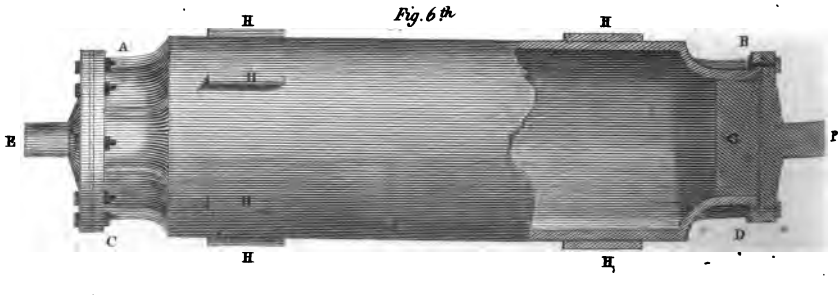


Fig. 6th



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GENERAL

EXPLANATION OF THE PLATES.

PLATE I. ESSAY I. IS DESCRIBED ON THE PLATE.

PLATE II.—ESSAY II.

On the Shafts of Mills and other Machines.

Fig. 1.—No. 1, No. 2, and No. 3.—Old mode of fixing gudgeons called *laid-in gudgeons*, art. 132, p. 256.

Fig. 2.—No. 1. and No. 2.—Cross-tailed gudgeons, art. 133, p. 257.

Fig. 3, Fig. 4, and Fig. 5.—Parts of cross-tailed gudgeons, art. 133, p. 257.

Fig. 6.—A hollow cast iron-shaft. No. 2, an end view to shew the manner of fixing the gudgeons, art. 135, p. 261.

PLATE III.—ESSAY II.

Fig. 7.—No. 1, No. 2, No. 3, and No. 4.—A feathered shaft, with different sections, art. 136, p. 262.

Fig. 8.—No. 1, and No. 2.—Square shafts, art. 136, p. 263.

Fig. 9.—No. 1, and No. 2.—Stress on shafts, art. 182, p. 350.

Fig. 9.—Water wheel with teeth on the shrouding, to give motion to the mill, art. 137, p. 265.

Fig. 10.—The chief strain on the vertical shaft is that which tends to twist it, art. 137, p. 265.

Fig. 11.—Example of a compound strain on the shaft, art. 137, p. 265.

Fig. 12.—Shaft of a water wheel, art. 137, p. 265, and art. [B. 191.] p. 361.

PLATE III.

Fig. 7.

Fig. 7. N°. 2.

Fig. 7. N°. 3.

Fig. 7. N°. 4.

Fig. 8. N°. 2.

Fig. 8.

Fig. 9. N°. 1.

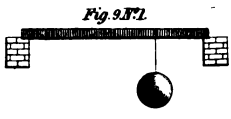
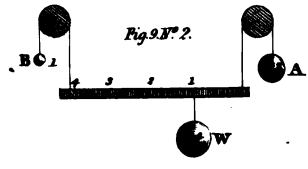


Fig. 9. N°. 2.



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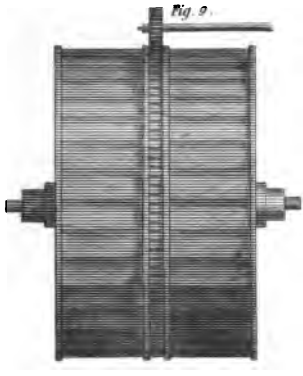

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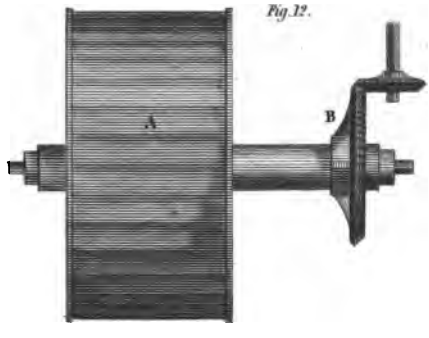
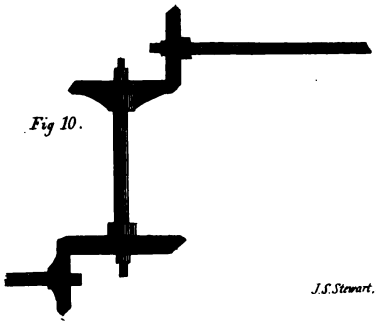


Fig 10.



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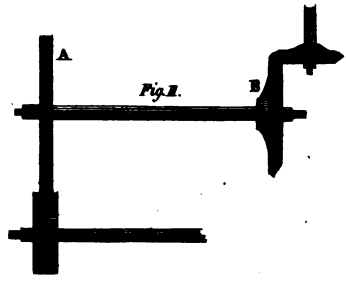

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PLATE IV.

Fig. 1st

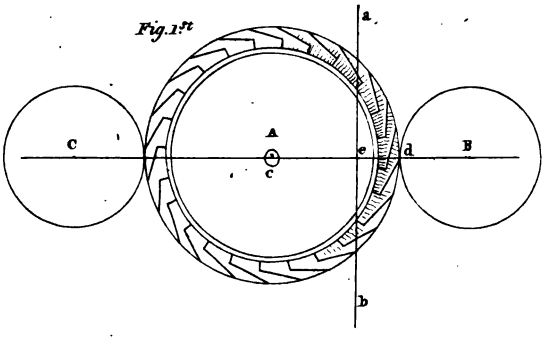


Fig. 2.

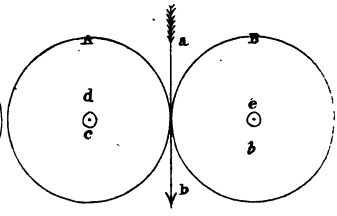


Fig. 4 N°1.

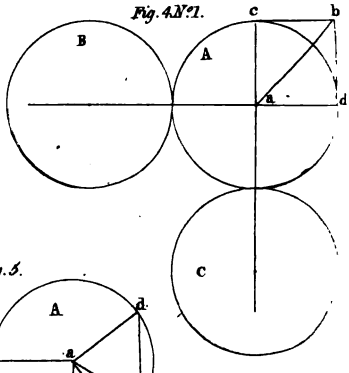
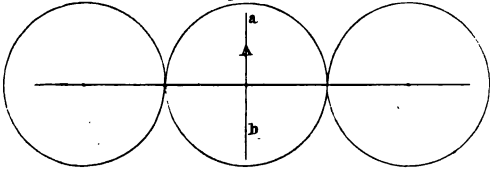


Fig. 3.



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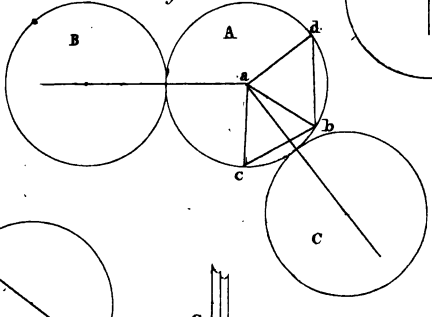
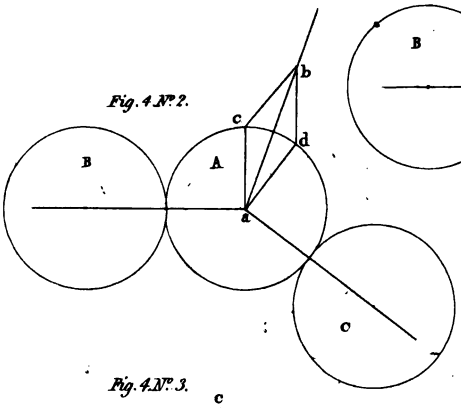


Fig. 4 N°2.



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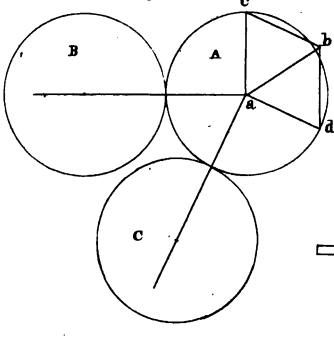

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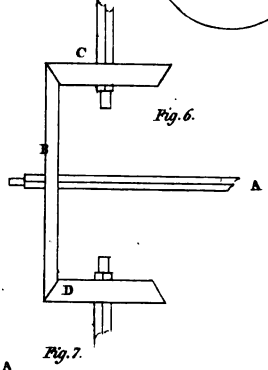

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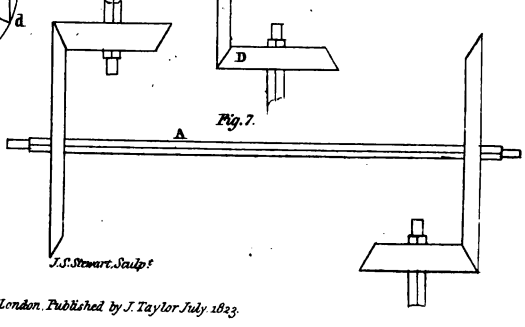

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PLATE IV.—ESSAY II.

Fig. 1.—Effect of position in causing a greater or less degree of strain on shafts, art. 138, p. 266.

Fig. 2.—Stress on shafts from the action of the moving power, art. 139, p. 267.

Fig. 3, Fig. 4.—No. 1, No. 2, No. 3, and Fig. 5.—Effect of position in causing more or less stress on the shafts, art. 140, p. 269.

Fig. 6, and Fig. 7.—To explain the effect of the place of a wheel on a shaft, art. 142, p. 271.

PLATE IV. A.—ESSAY II.

Fig. 1, Fig. 2, Fig. 3.—Represent an improved method of fixing gudgeons on wooden shafts, art. [B. 133.] p. 259.

Fig. 4.—Plan of a shaft and wheels to show how the stress on a shaft may be determined, art. [A. 149.] p. 285—288.

Fig. 5, Fig. 6, and Fig. 7.—Figures to show the stress on shafts and gudgeons in different circumstances, art. [D. 149.] p. 289.

Fig. 1.

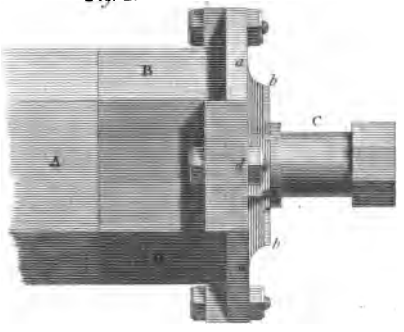


Fig. 2.

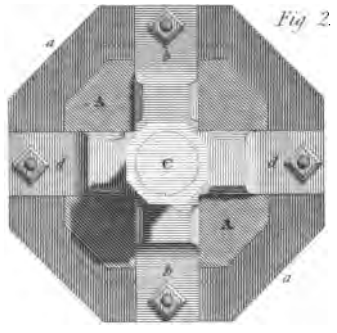
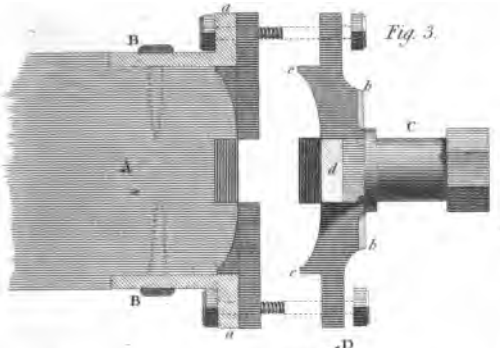


Fig. 3.



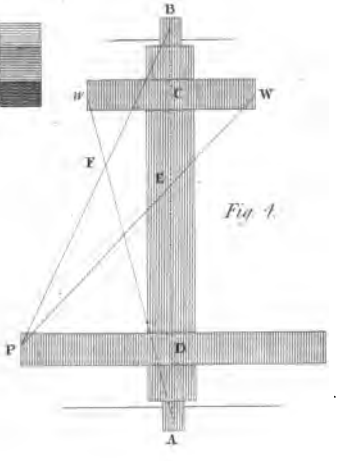
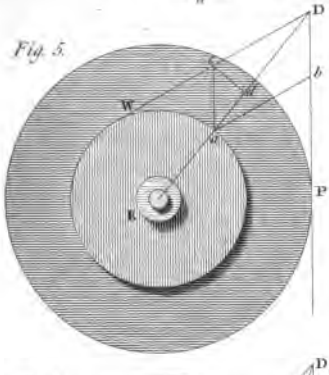


Fig. 4.

Fig. 5.



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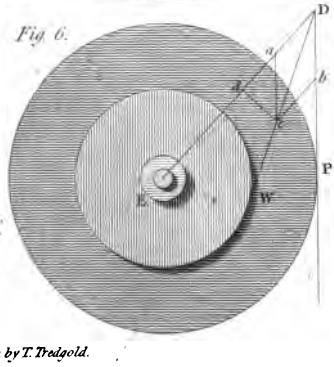
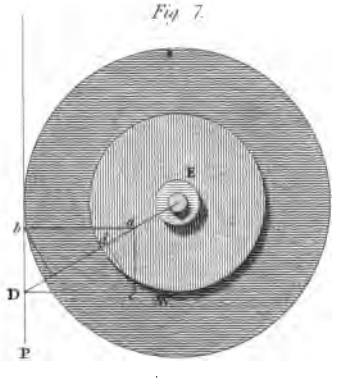


Fig. 7.



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Essay. 3.

PLATE V.

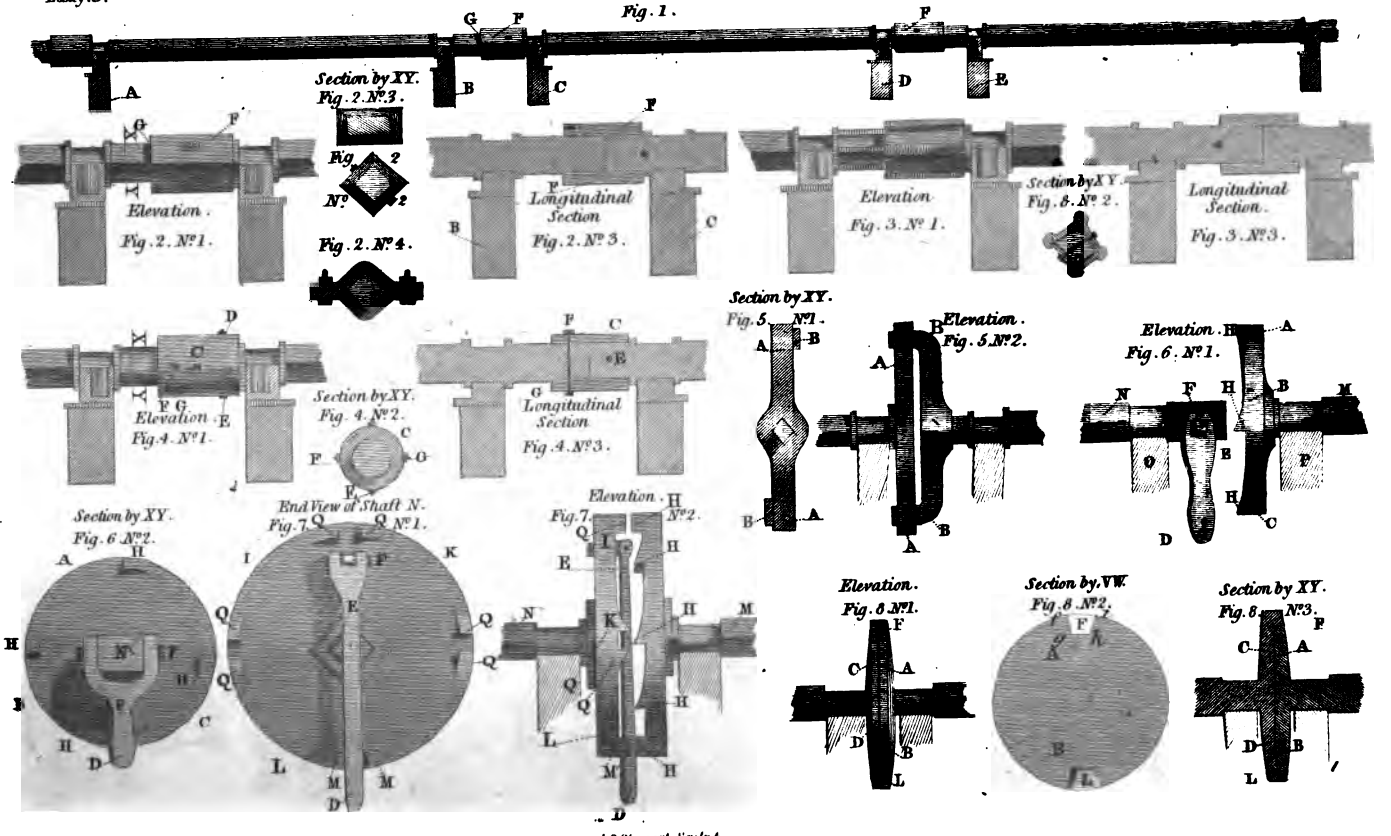

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PLATE V.—ESSAY III.

On the Longitudinal Connexion of Shafts, denominated Couplings.

Fig. 1 —Represents three shafts connected by couplings, supported by double bearings, art. 210, p. 408.

Fig. 2.—No. 1, and No. 2.—The square coupling, with double bearings, art. 210, p. 409.

————No. 3.—A different modification of the square coupling, art. 210, p. 409.

————No. 4.—A coupling box made in two pieces, art. 210, p. 410.

Fig. 3.—No. 1, No. 2, and No. 3.—A variety of the couplings with double bearings, art. 212, p. 411.

Fig. 4.—No. 1, No. 2, and No. 3.—The round coupling, art. 213, p. 411.

Fig. 5.—No. 1, and No. 2.—Clutches or glands, art. 215, p. 413.

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Fig. 7.—No. 1, and No. 2.—Boring-mill clutch, second construction, art. 221, p. 416.

Fig. 8.—No. 1, No. 2, and No. 3.—Coupling having circular plates, art. 224, p. 418.

PLATE VI.—ESSAY III.

Fig. 9.—No. 1, and No. 2.—Coupling-link used by Messrs. Boulton and Watt in their portable steam engines, art. 226, p. 419.

Fig. 10.—No. 1, No. 2, and No. 3.—A coupling sometimes used to connect the fly-wheel shaft of a steam engine with the mill work, and is so contrived, that in case the fly should turn in a wrong direction, the mill work remains at rest, art. 228, p. 420.

Fig. 11.—The universal joint, art. 232, p. 424.

Fig. 12.—No. 1, No. 2, and No. 3.—Square coupling, having one bearing, art. 236, p. 426.

Fig. 13.—No. 1, and No. 2.—Mode of coupling rollers used in machinery for spinning cotton, art. 239, p. 429.

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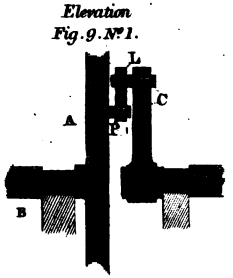
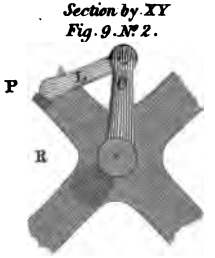
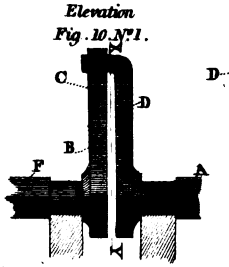
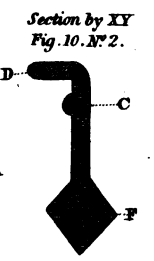
Fig. 14.—Bolted Coupling, used in some mills in Manchester, art. 241, p. 430.

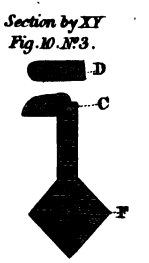
PLATE VI.

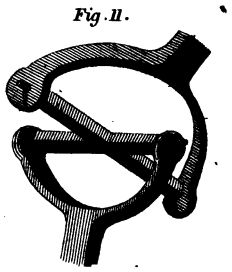


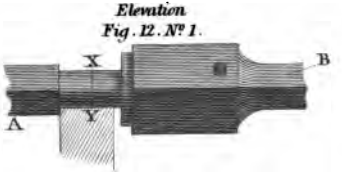


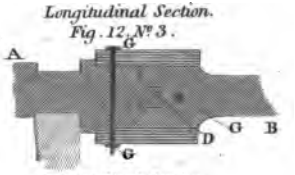


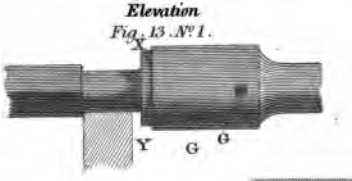


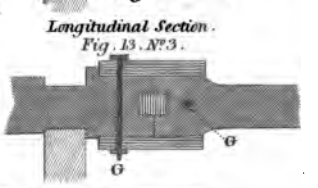


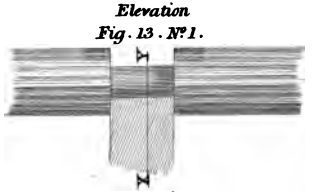


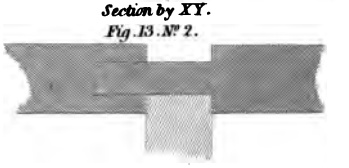












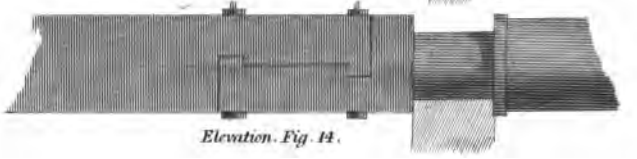


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PLATE VII.

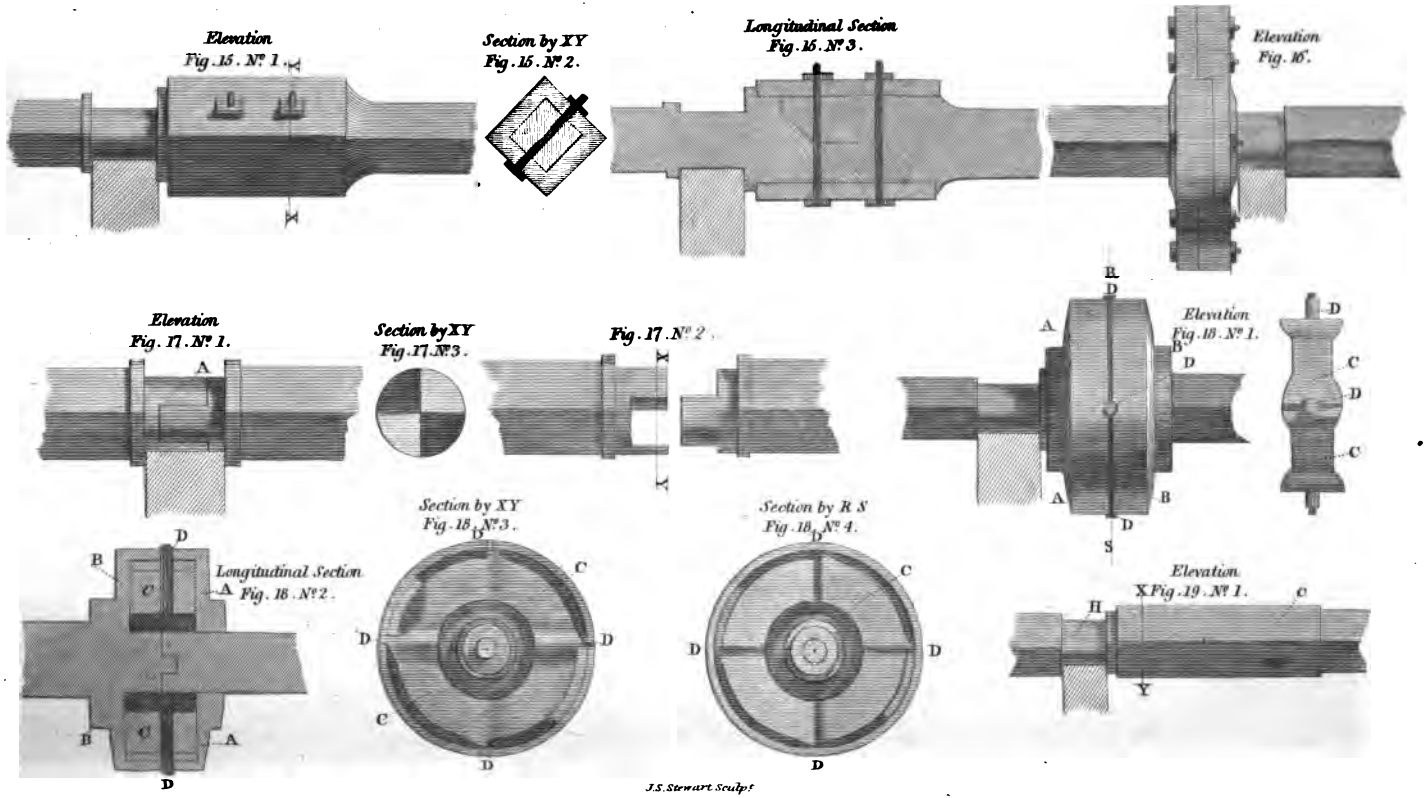

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PLATE VII.—ESSAY III.

Fig. 15.—No. 1, No. 2, and No. 3.—A variety of the bolted coupling, art. 243, p. 430.

Fig. 16.—Another modification of the bolted coupling, art. 244, p. 431.

Fig. 17.—No. 1, No. 2, and No. 3.—Quadrant coupling, art. 245, p. 431.

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Fig. 19.—No. 1.—Elevation of coupling, executed at Manchester, art. 249, p. 434. No. 2, and No. 3, are on the next plate.

PLATE VIII.—ESSAY III.

Fig. 19.—No. 2, and No. 3.—Sections of couplings executed at Manchester, art. 249, p. 434. No. 1, is on the preceding plate.

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Fig. 21².—Lying shafts, shewing the situation of the couplings with regard to the wheels, art. 263, p. 441.

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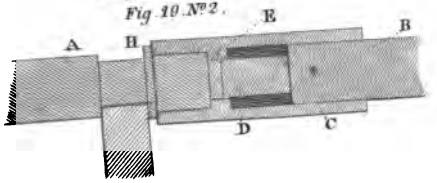
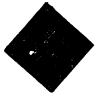
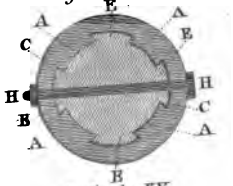
Longitudinal Section
Fig. 19. N°2.



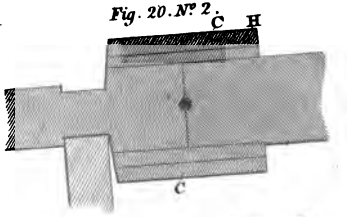
Section by XY.
Fig. 19. N°3.



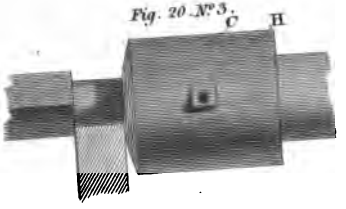
Section by XY.
Fig. 20. N°1.



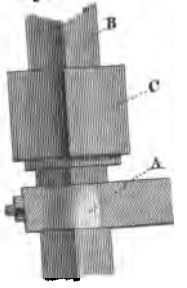
Longitudinal Section
Fig. 20. N° 2.



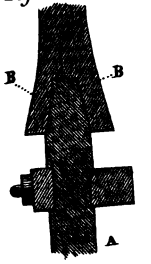
Elevation.
Fig. 20. N° 3.



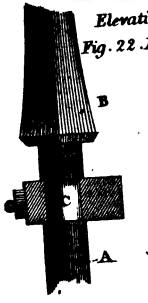
Elevation
Fig. 21.



Section by XY.
Fig. 22. N°1.



Elevation
Fig. 22. N° 2.



Elevation
Fig. 23. N°1.

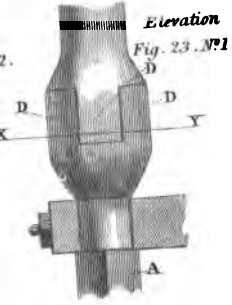


Fig. 21.

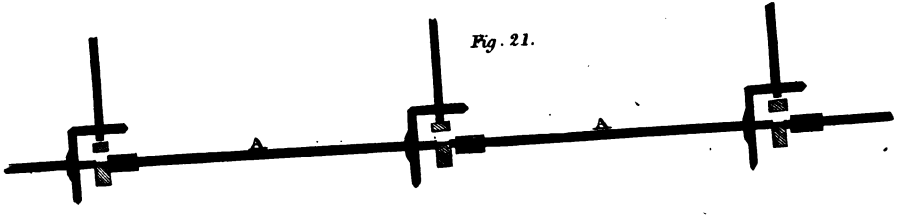


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PLATE IX.

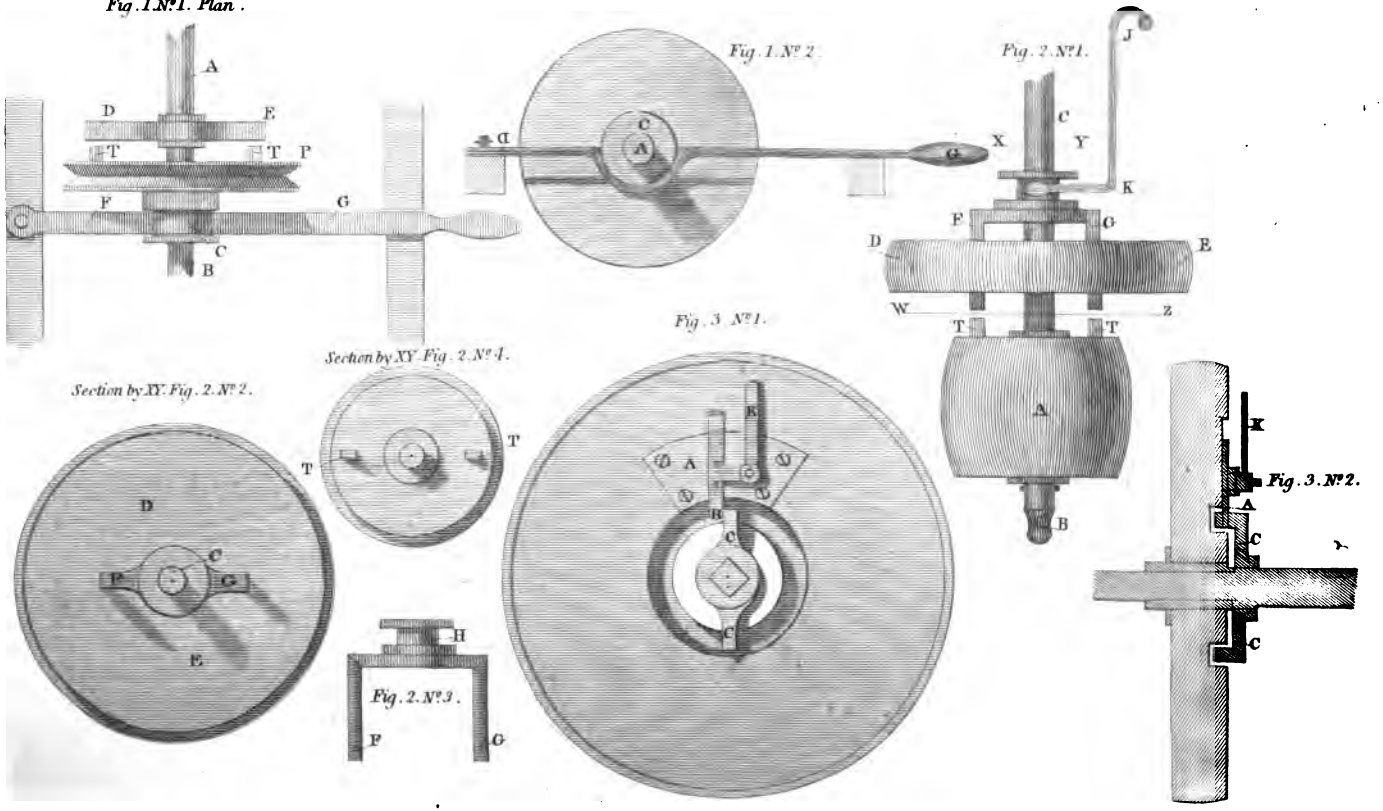

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PLATE IX.—ESSAY IV.

On Methods of Disengaging and Re-engaging Machinery, while in Motion.

Fig. 1, and No. 2.—The sliding pulley, art. 280, p. 456.

Fig. 2.—No. 1, No. 2, No. 3, and No. 4.—The bayonet, art. 282, p. 458.

Fig. 3.—No. 1, and No. 2.—The lock pulley, art. 284, p. 460.

PLATE X.—ESSAY IV.

Fig. 4.—No. 1, and No. 2.—Fast and loose pulleys, or dead and live pulleys, art. 286, p. 461.

Fig. 5.—Sack tackle, art. 289, p. 463.

Eig. 6.—No. 1.—Wheels, *in gear*, having a moveable bridge, art. 292, p. 465. No. 2, is on the next plate.

PLATE X.

Fig. 4. N°1.

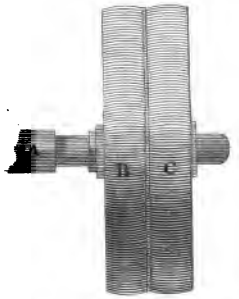

Fig. 4. N° 2.

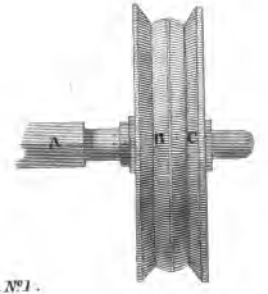

Fig. 5.

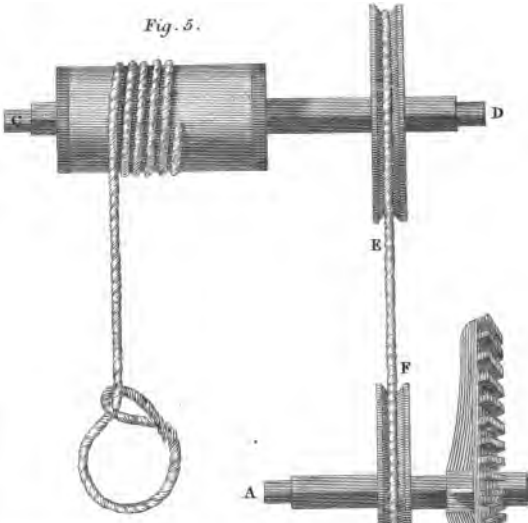

Fig. 6. N°1.

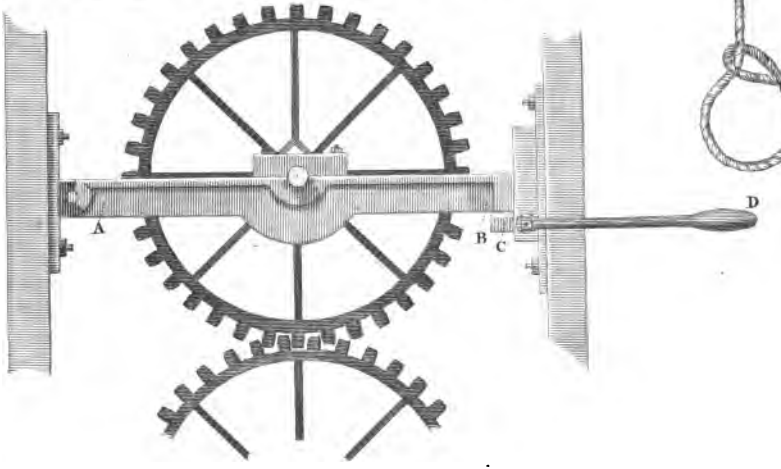

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Fig. 6. № 2.

PLATE XI.

Fig. 7. № 1.

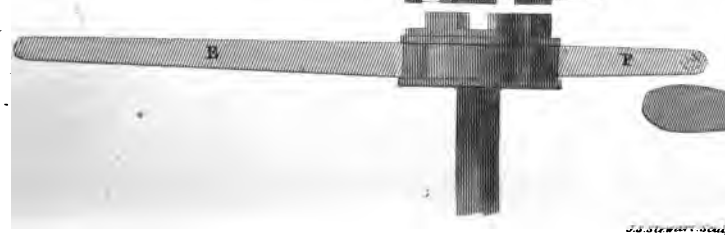

Fig. 8. № 1.

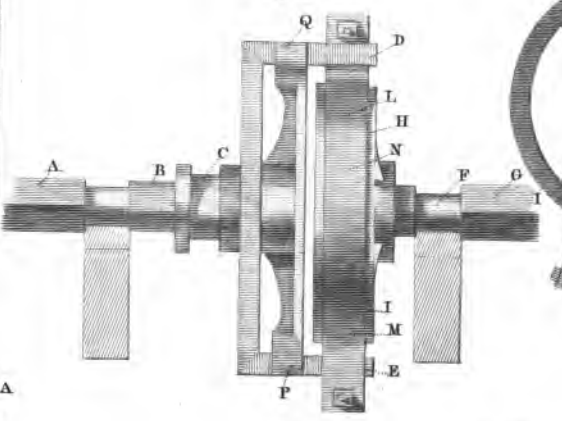

Fig. 8. № 2.

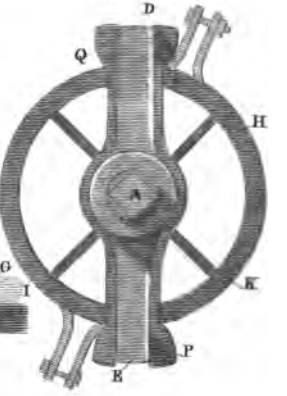

Fig. 7. № 2.

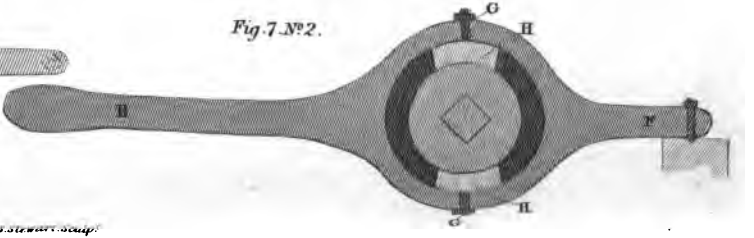

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PLATE XI.—ESSAY IV.

Fig. 6.—No. 2.—Wheels *out of gear*, art. 292, p. 465. No. 1, is on the preceding plate.

Fig. 7.—No. 1, and No. 2.—Clutch for engaging the wheel A with the shaft B, art. 294, p. 466.

Fig. 8.—No. 1, and No. 2.—Friction clutch, art. 296, p. 468. No. 3, is on the next plate.

PLATE XII.—ESSAY IV.

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Fig. 9.—No. 1, and No. 2.—Friction cones, art. 298, p. 470.

Fig. 10.—No. 1, and No. 2.—Wheels moving by contaction, art. 300, p. 471.

Fig. 11.—Sack tackle, art. 303, p. 472.

Fig. 12.—No. 1, and No. 2.—Self-disengaging coupling, art. 305, p. 473.

PLATE XII.

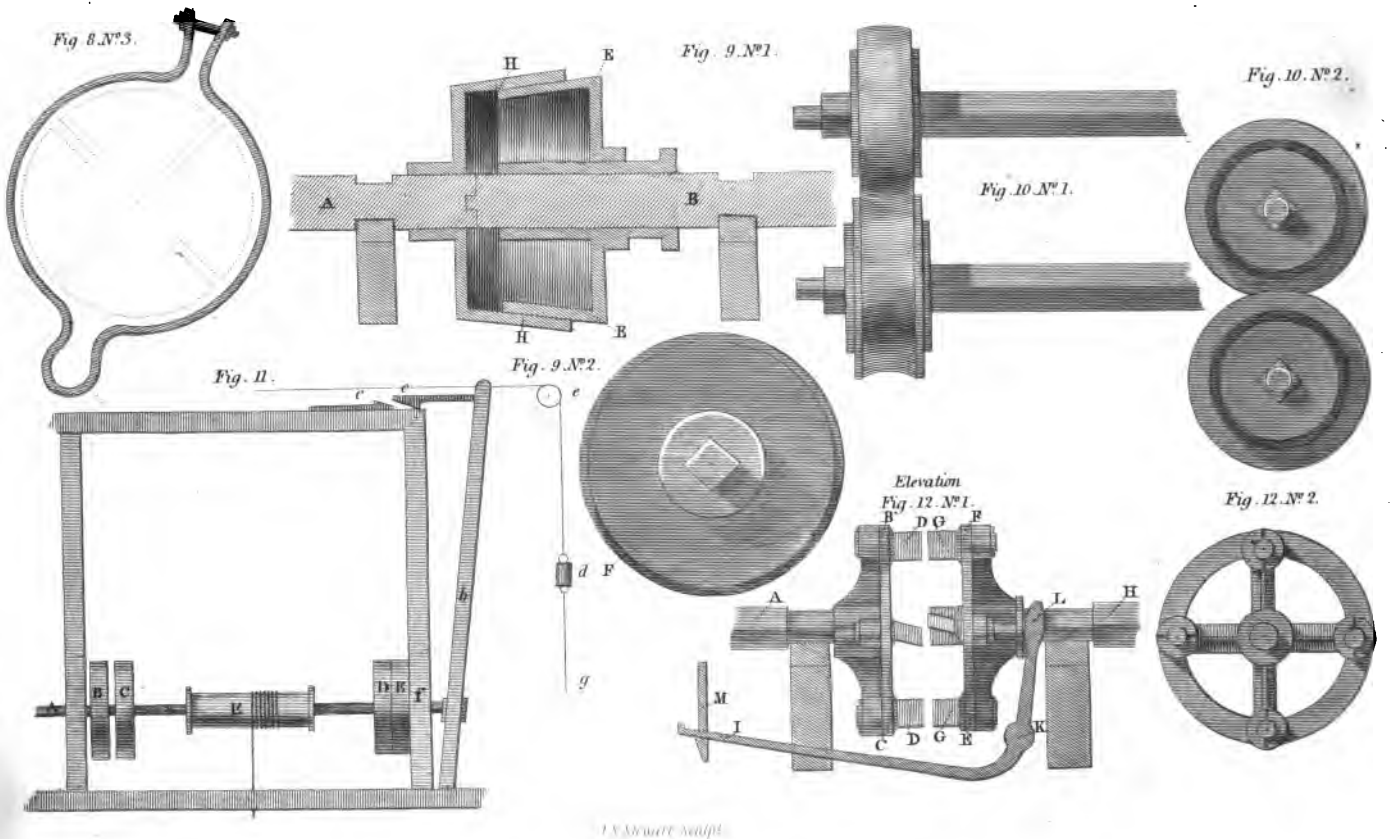
Fig. 8. N°. 3.
Fig. 9. N°. 1.
H
E
A
B
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Fig. 10. N°. 2.
Fig. 10. N°. 1.
Fig. 11.
Fig. 9. N°. 2.
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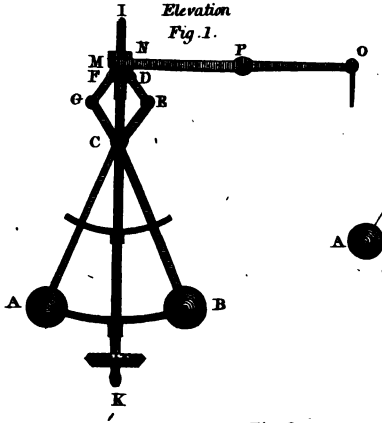
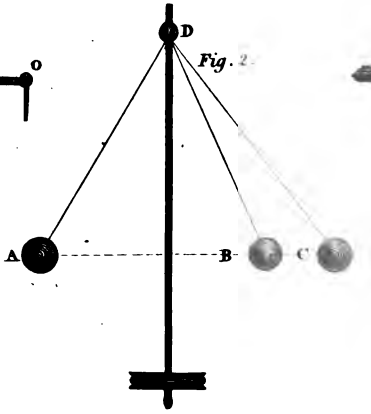
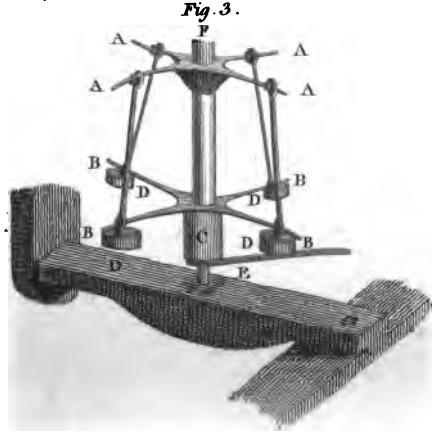
E
F
Elevation
Fig. 12. N°. 1.
B
D
G
F
A
L
H
M
I
C
D
G
E
K
Fig. 12. N°. 2.

PLATE XIII.







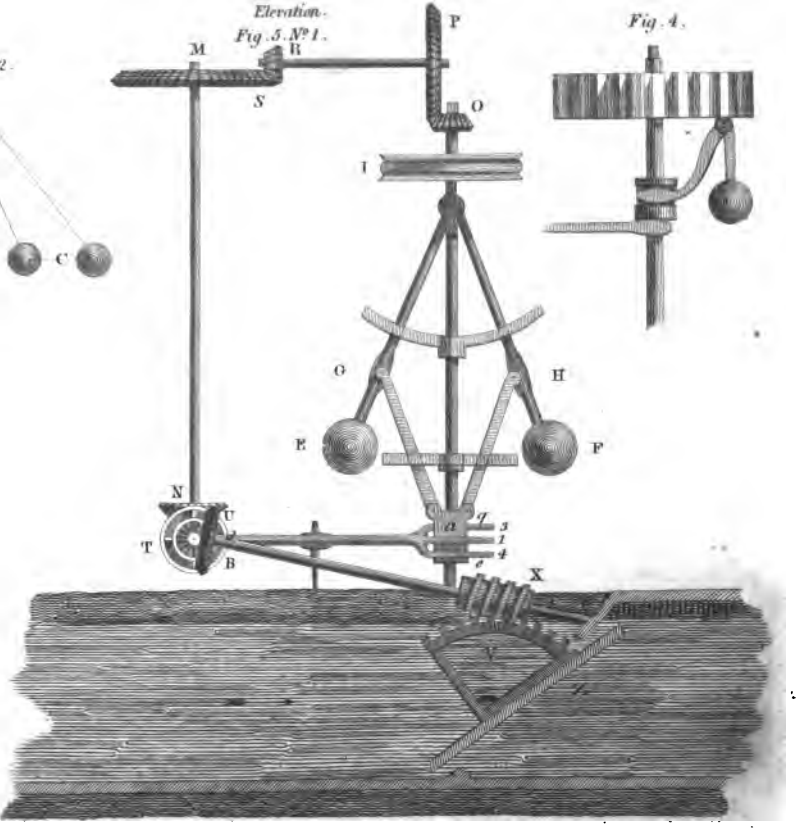


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PLATE XIII.—ESSAY V.

On Mechanism for Equalizing the Motion of Mills, denominated Lift Tenters, Engine Governors, and Water-Wheel Governors.

Fig. 1.—Steam-engine governor, art. 307, p. 481.

Fig. 2.—The balls A B and C being made to revolve, are all found on the same horizontal plane, art. 310, p. 484.

Fig. 3.—Lift-tenters for wind mill, first construction, art. 315, p. 486.

Fig. 4.—Lift-tenter, second construction, art. 316, p. 487.

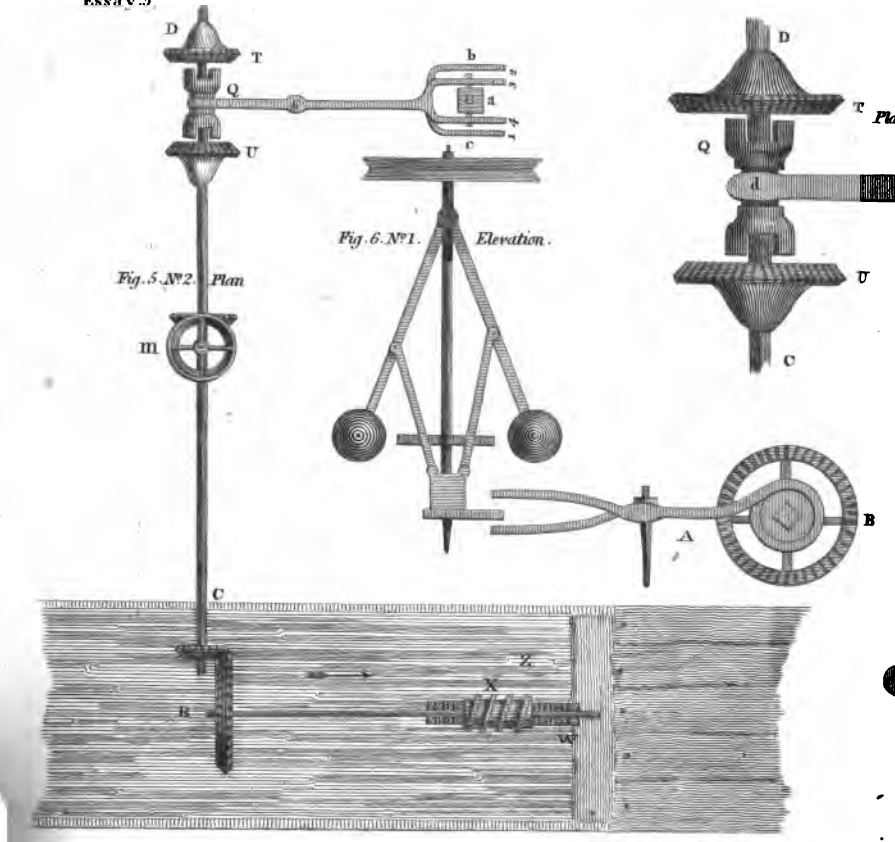
Fig. 5.—No. 1.—Elevation of water-wheel governor, first construction, art. 318, p. 489. No. 2, No. 3, and No. 4, of Fig. 5, are on the next plate.

PLATE XIV.—ESSAY V.

Fig. 5.—No. 2, No. 3, and No. 4.—Water-wheel governor, first construction, art. 318, p. 489. No. 1, of Fig. 5, is on Plate XIII.

Fig. 6.—No. 1, and No. 2.—Water-wheel governor, second construction, art 320, p. 493.

PLATE. XIV.



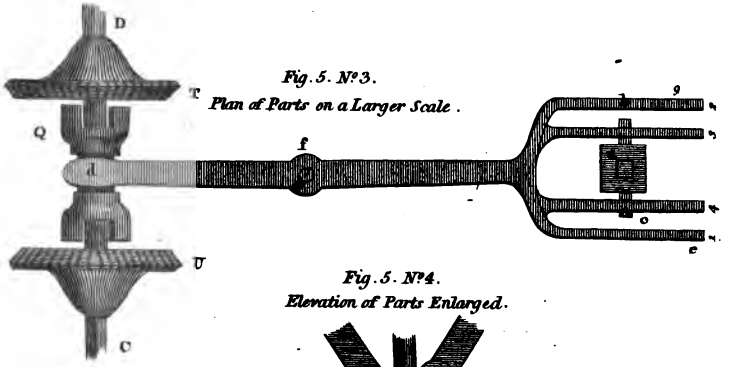
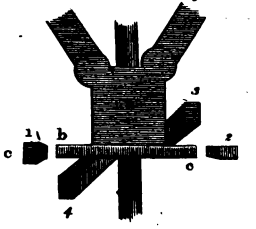


Fig. 5. Nº3.
Plan of Parts on a Larger Scale.

Fig. 5. Nº4.
Elevation of Parts Enlarged.



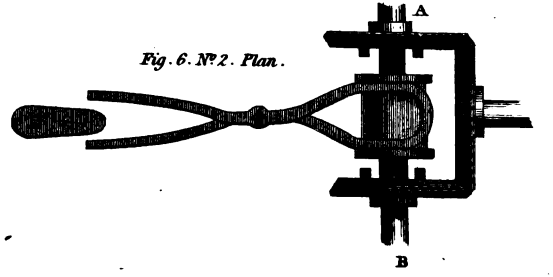


Fig. 6. Nº2. Plan.

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PLATE XIV.—ESSAY V.

Fig. 5.—No. 2, No. 3, and No. 4.—Water-wheel governor, first construction, art. 318, p. 489. No. 1, of Fig. 5, is on Plate XIII.

Fig. 6.—No. 1, and No. 2.—Water-wheel governor, second construction, art 320, p. 493.

PLATE. XIV.

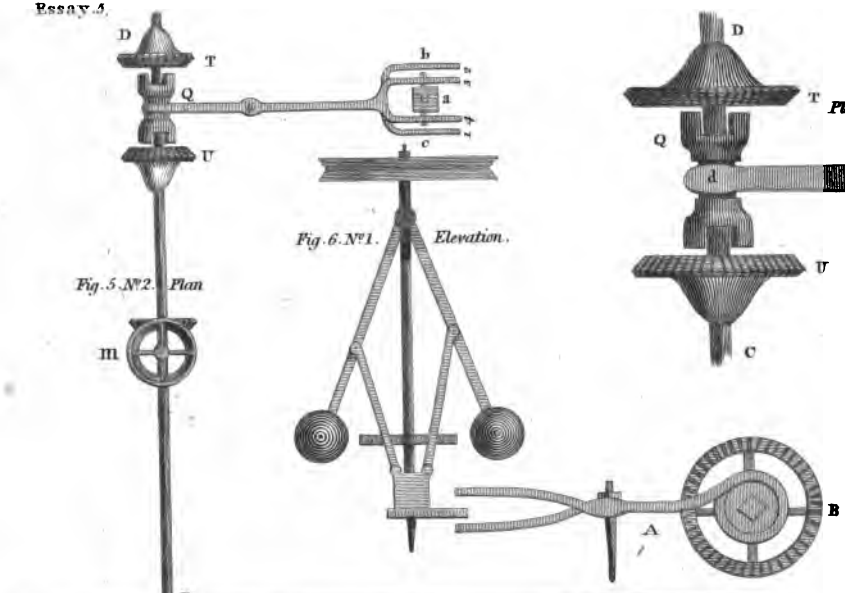

Fig. 6. Nº 1. Elevation.

Fig. 5. Nº 2. Plan

Fig. 5. Nº 3.
Plan of Parts on a Larger Scale.

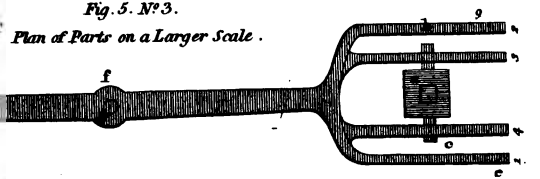

Fig. 5. Nº 4.
Elevation of Parts Enlarged.

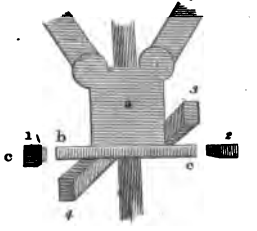

Fig. 6. Nº 2. Plan.

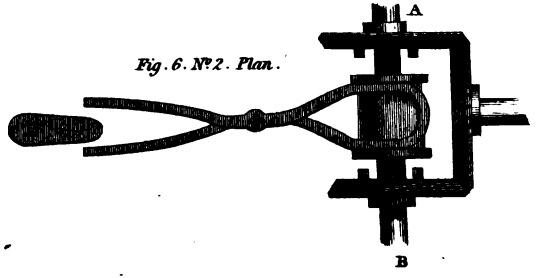

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PLATE XV.

Essay.5.

Fig.7. Elevation.

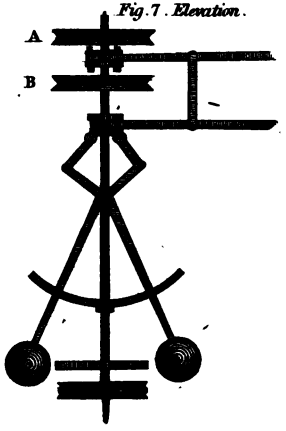

Fig.8.N°1. Elevation.

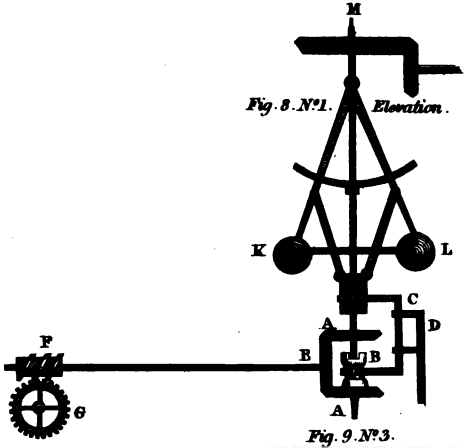

Fig.8.N°2.

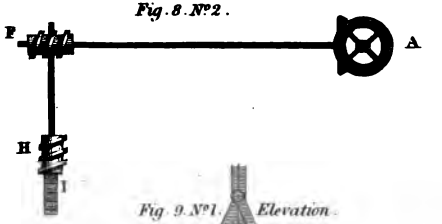

Fig.9.N°1. Elevation.

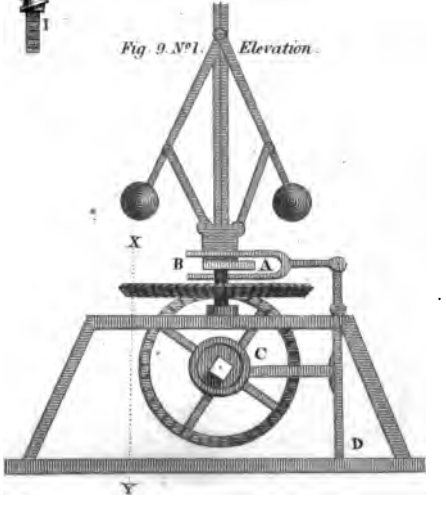

Fig.9.N°2.Plan.

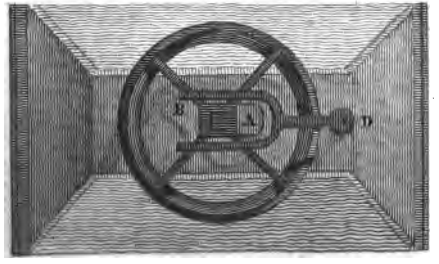

Fig.9.N°3.
Section by the Line XY.

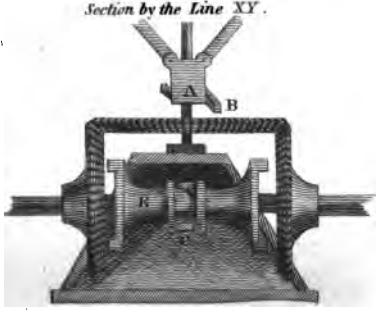

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Fig. 7.—Water-wheel governor, third construction, art 321, p. 494.

Fig. 8.—No. 1, and No. 2.—Water-wheel governor, fourth construction, art. 322, p. 494.

Fig. 9.—No. 1, No. 2, and No. 3.—Water-wheel governor, fifth construction, art. 323, p. 496.

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On Changing the Velocity of Machinery while in Motion.

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Fig. 2.—Alternate cones, art. 332, p. 531.

Fig. 3.—Wheels moving by contaction, art. 334, p. 532.

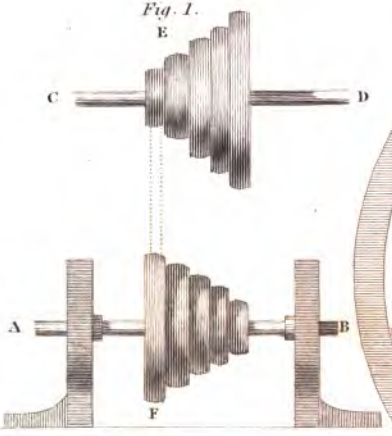
Fig. 6.—No. 1, and No. 2.—Mechanism used in cotton spinning called a double speed, third construction, art. 341, p. 530.

Fig. 4, and Fig. 5, are on Plate XVII.

PLATE XVI.

Elevation. Fig. 6. N° 2.

Fig. 1.



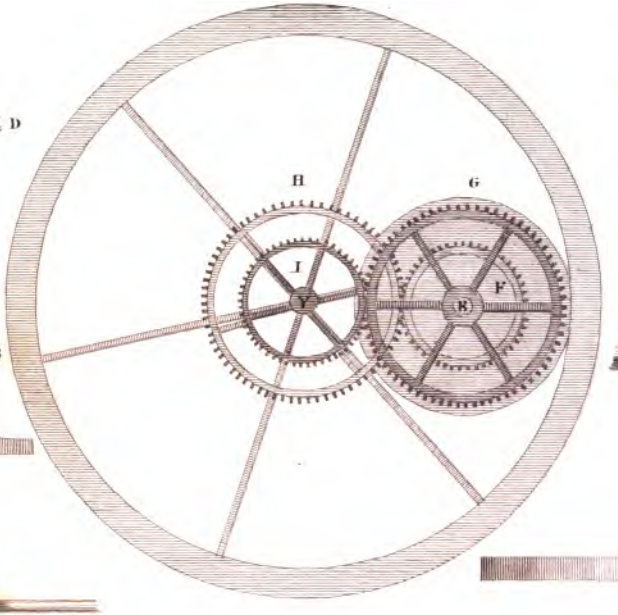


Fig. 2.

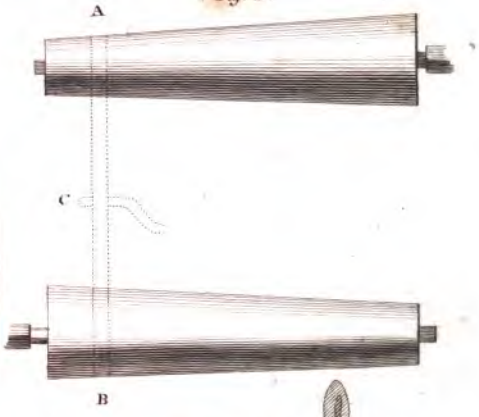


Fig. 3.

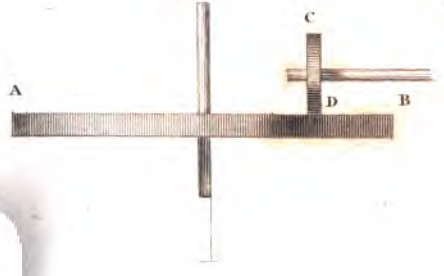


Fig. 6. N°1. Plan.

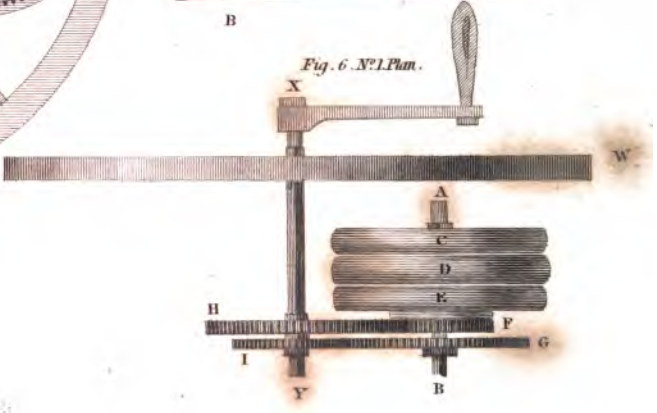


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PLATE XVII.

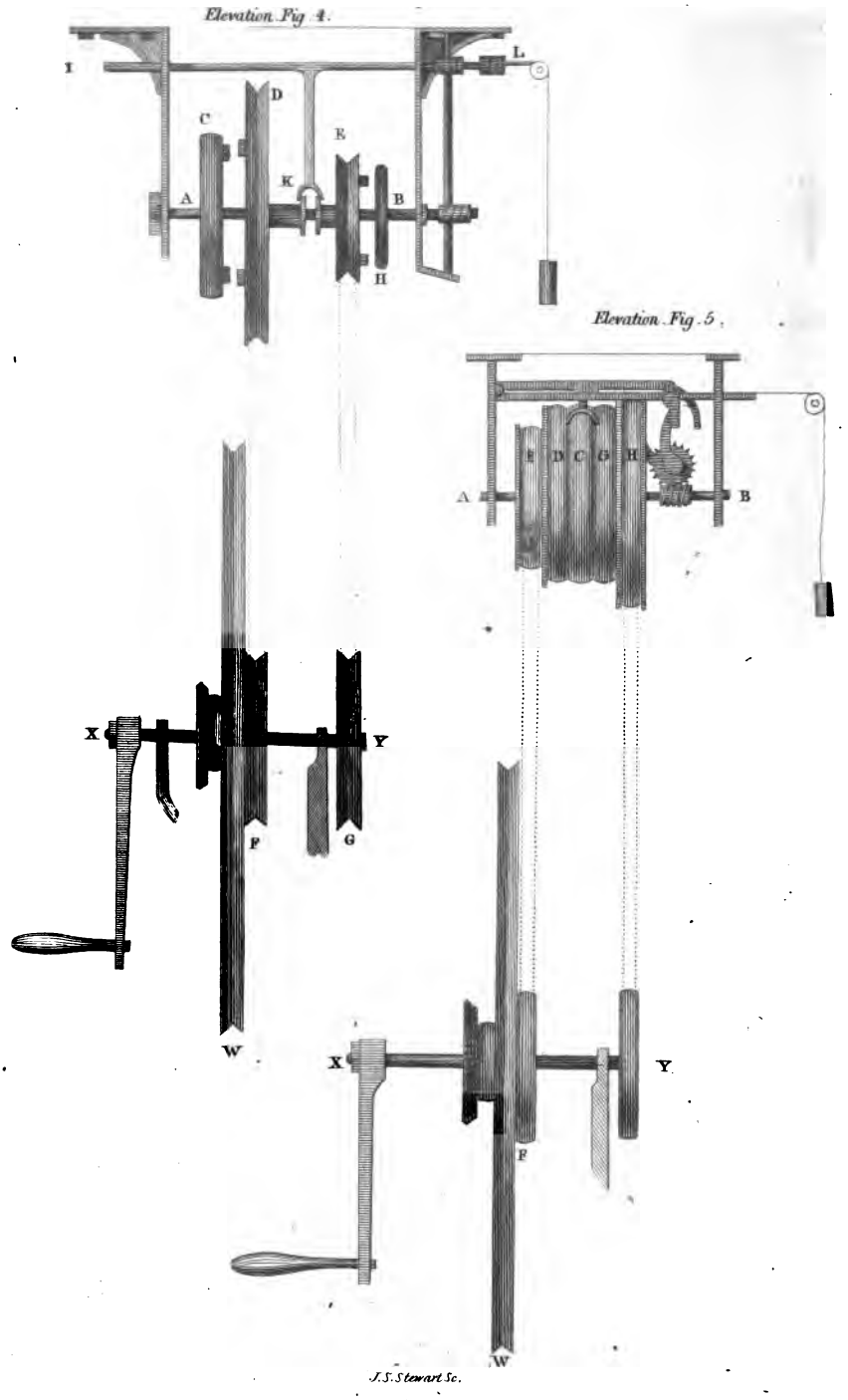

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PLATE XVII.—ESSAY VI.

Fig. 4.—Double speed, first construction, art. 337, p. 535.

Fig. 5.—Double speed, second construction, art. 339, p. 537.

PLATE XVIII.—ESSAY VII.

On the Framing of Mill Work.

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Fig. 2.—No. 1, No, 2, No. 3.—Pivot of upright shaft having a steel foot, art. 350, p. 551.

Fig. 3.—Cylindrical steel pivot, art. 351, p. 551.

Fig. 4.—No. 1, No. 2, and No, 3.—Journal of upright shaft supported by a breast, art. 354, p. 553.

Fig. 5.—Millstone bush, art. 355, p. 553.

Fig. 6.—No. 1, No. 2, No. 3.—Headstock framing for supporting gudgeons of water wheel, art. 356, p. 554.

Fig. 7.—No. 1, No. 2, No. 3, and No. 4.—Wooden framing for lying shafts, art. 357, p. 555.

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Fig. 10.—No. 1, and No. 2.—Bridge and pedestal of upright shaft, art. 359, p. 556.

Fig. 11.—Wooden framing of an upright and lying shaft connected by bevelled wheels, art. 360, p. 556.

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Fig. 20.—No. 1, and No. 2.—Bridge made of cast iron for sustaining lying shaft, art. 368, p. 563.

Essay.7. PLATE. XVIII

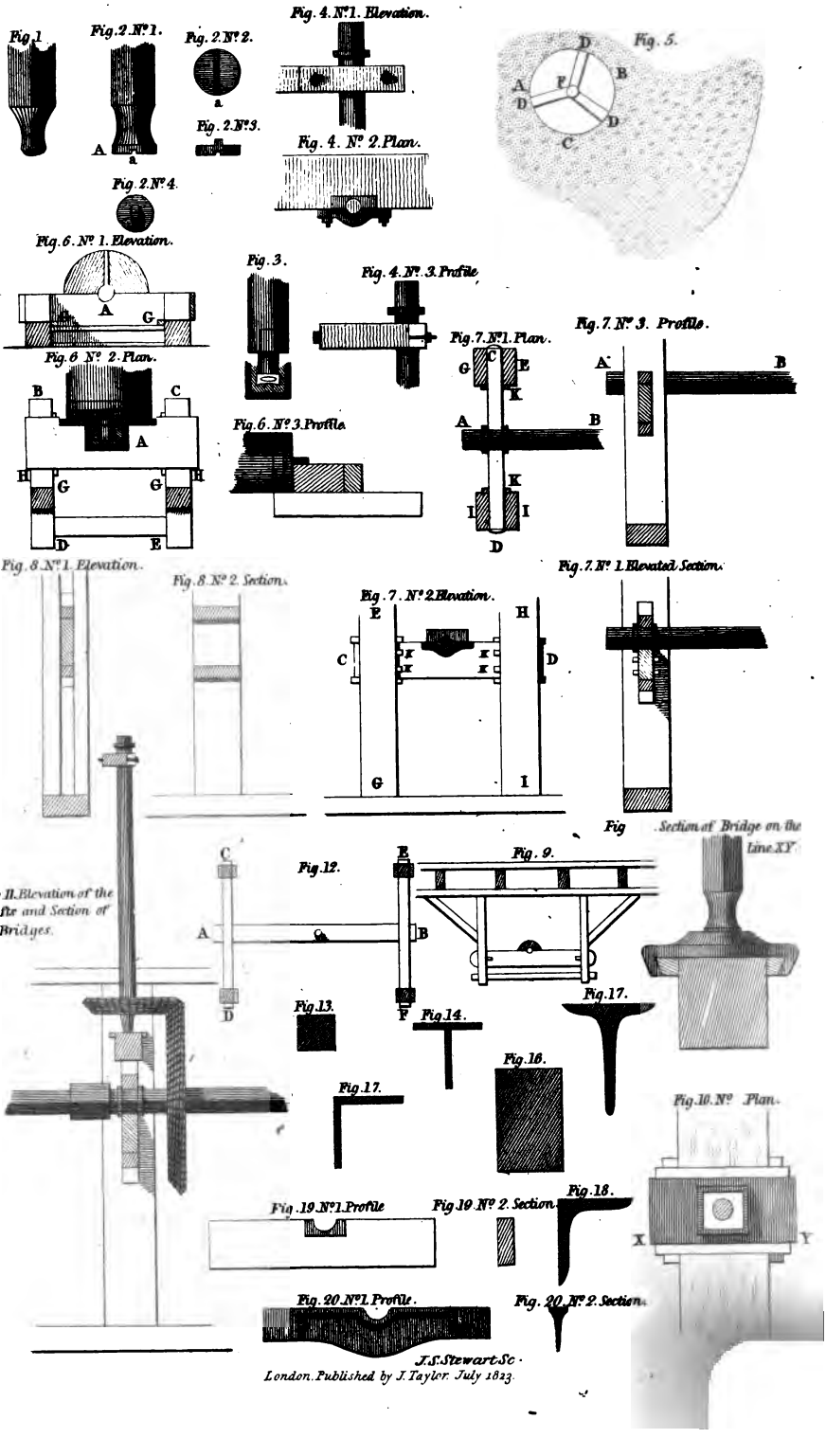

Fig.11.Elevation of the Shafts and Section of the Bridges.

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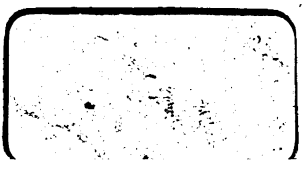
204 Bottom line *for* $2\left(\frac{H}{v}\right)^{\frac{1}{2}}$ *read* $2\left(\frac{H}{v}\right)^{\frac{1}{3}}$.

387 Top line *for* Locus *read* Locust.

— Line 3 *for* Beech Oak *read* Beech, Oak.

519 Line 6 from bottom *for* than *read* that.

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